ARMY RESEARCH LABORATORY

Evaluation of an Army Aviator's Ability to Conduct Ingress and Egress of the RAH-66 Comanche Crew Station While Wearing the Air Warrior Ensemble

by Joshua S. Kennedy, David B. Durbin, JimA. Faughn,
Richard W. Kozycki, and Kyle J. Nebel

ARL-TR-3404 December 2004

NOTICES

Disclaimers

Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5425

ARL-TR-3404 **December 2004**

Evaluation of an Army Aviator's Ability to Conduct Ingress and Egress of the RAH-66 Comanche Crew Station While Wearing the Air Warrior Ensemble

Joshua S. Kennedy, David B. Durbin, Jim A. Faughn, and Richard W. Kozycki
Human Research and Engineering Directorate, ARL

Kyle J. Nebel
U.S. Army Tank-Automotive Research, Development, and Engineering Center

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED (From - To)**
December 2004		July 2003

4. TITLE AND SUBTITLE

Evaluation of an Army Aviator's Ability to Conduct Ingress and Egress of the RAH-66 Comanche Crew Station While Wearing the Air Warrior Ensemble

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Joshua S. Kennedy, David B. Durbin, Jim A. Faughn, and Richard W. Kozycki (all of ARL); Kyle J. Nebel (TARDEC)

5d. PROJECT NUMBER

62716AH70

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Research Laboratory
Human Research and Engineering Directorate
Aberdeen Proving Ground, MD 21005-5425

8. PERFORMING ORGANIZATION REPORT NUMBER

ARL-TR-3404

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The RAH-66 Comanche represented the U.S. Army's next generation state-of-the-art armed reconnaissance helicopter. Likewise, the Air Warrior aviation life support ensemble worn by Army aviators represents a significant improvement in personal clothing and equipment. However, at the intersection of the Comanche's crew stations and the bulkiness of the Air Warrior ensemble lies a potential problem: pilots have difficulty entering and leaving the crew station, especially in an emergency. This study evaluated an Army aviator's ability to conduct ingress and egress of the Comanche while wearing the Air Warrior ensemble. Several operationally relevant combinations of aircrew anthropometry, Air Warrior ensembles, and ingress-egress routes were evaluated for the front and rear crew stations. Jack human-figure modeling and motion capture technology were also used in the evaluation. Mean emergency egress times were found to be well within published military specifications. However, results show that larger males will likely have a significantly more difficult time leaving the aircraft than smaller persons, especially when clothed in the bulkiest Air Warrior configuration. Several operational and design recommendations are made. In February 2004, the Department of the Army cancelled the RAH-66 Comanche program. However, the information contained in this report can be used for ingress and egress testing of new or modified aviation systems.

15. SUBJECT TERMS

pilot-vehicle interface; pilot workload; RAH-66 Comanche; ingress; emergency egress; Air Warrior

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					Joshua S. Kennedy
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	UL	85	**19b. TELEPHONE NUMBER** *(Include area code)*
Unclassified	Unclassified	Unclassified			831-656-2786

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

List of Tables

Acknowledgments

We are extremely grateful for the aid of many professionals during the course of this evaluation. From Sikorsky, thanks go to Steve Ratka, Mike D'Louhy, Dave Wickman, and John Upton. All three proved invaluable in the preparation and execution of the evaluation.

From the crew at the Human Research and Engineering Directorate of the U.S. Army Research Laboratory, Aberdeen Proving Ground, Maryland, thanks go to Dennis Hash and Nick Keenan for excellent craftsmanship in preparing the Comanche structural test article for ingress-egress testing. In addition, Mike Kosinksi spent many hours converting CAD (computer-aided design) files and making the drawings needed to build the mock-up. We also thank to Ron Carty for his outstanding videographic work which will leave us a lasting record of the event.

We are grateful to our peer reviewers for their time, attention, and expertise: Dr. Mary Ann Valk of Sikorsky; Mr. Scott Solomon of AMCOM Aviation Engineering Directorate, and Mr. Ron Ferrell of the Comanche Program Manager's Office. From Redstone Arsenal, thanks go to Tim Jones from the Air Warrior Program Manager's Office for his expertise in fitting our subjects. Also helping was Betty Dart from Natick Labs. Both Ron Ferrell and Scott Solomon provided invaluable aid and expertise during the evaluation.

Finally and most importantly, a hearty appreciation to our four participants, who shall remain unnamed because of scientific protocol reasons. Professional Army aviators all, they and their comrades are the reason that all of us work so diligently on these systems.

1. Introduction

1.1 Background

The RAH[1]-66 Comanche was designed to be a fully integrated, lightweight, twin-engine, two-pilot, advanced technology helicopter weapons system designed to project, protect, and sustain the Army. It was intended to gain information dominance, shape the battlespace, and conduct decisive operations. The Comanche's features included lightweight composite airframe structures; protected anti-torque systems; low-vibration, high-reliability rotor systems; reduced radar cross section (RCS) and infrared (IR) signatures; built-in diagnostics and-or prognostics; second generation target acquisition; night vision sensors; and a radar system.

The Comanche, like the AH-1 Cobra and AH-64 Apache before it, used a tandem seating configuration in which one aircrew member sits behind the other (see figure 1). This seating configuration is common among the world's attack helicopters and most fighter aircraft that use two pilots. In contrast, the side-by-side seating used in many other helicopter types, both U.S. and foreign, places pilots sitting next to one another in the crew station. This seating configuration is used mainly for troop transport and cargo aircraft and is also used for probably every commercial fixed wing airplane in the world. The primary reasons for the tandem seating arrangement are a smaller "head-on" target for enemy weapons systems and a smaller radar signature. The Comanche had been in development since the mid-1980s. In February 2004, the Department of the Army decided to cancel the RAH-66 Comanche program.

In terms of crew station ingress and egress, past experience and published literature (discussed in section 2) clearly demonstrate that the tandem seating configuration is by far the more difficult. The cramped, streamlined crew station is made to be *sat in* so that pilots can *fight from* its interior. The disadvantage is that it can be difficult to conduct ingress and egress of the aircraft. This is especially important during emergency egress situations when the two pilots must leave their crew station as soon as possible to save their own lives. In addition, it is a major design challenge to accommodate the disparate anthropometric requirements (small female to large male) and still meet cost and weight goals for the aircraft.

In addition to the difficulties presented by the cramped crew station design, a pilot's personal clothing and equipment will have a major impact on his or her ability to conduct ingress and egress of the crew station. The U.S. Army is developing, in addition to the Comanche, an aviation life support equipment (ALSE) system called the Air Warrior (AW) ensemble. Air Warrior is designed to replace and integrate a variety of older components of life support equipment and thereby enhance combat usefulness and decrease overall bulk of the ensemble. The AW program is being developed in three separate blocks. Block 1 focuses on integrating

[1]RAH = reconnaissance attack helicopter.

current technologies into a tailorable, effective system. Blocks 2 and 3 will take advantage of future technology to streamline the overall system (Department of the Army, 2003). Despite its very thorough and inspired design, Block 1 is still relatively bulky and presents difficulties for the ingress and egress of a helicopter crew station.

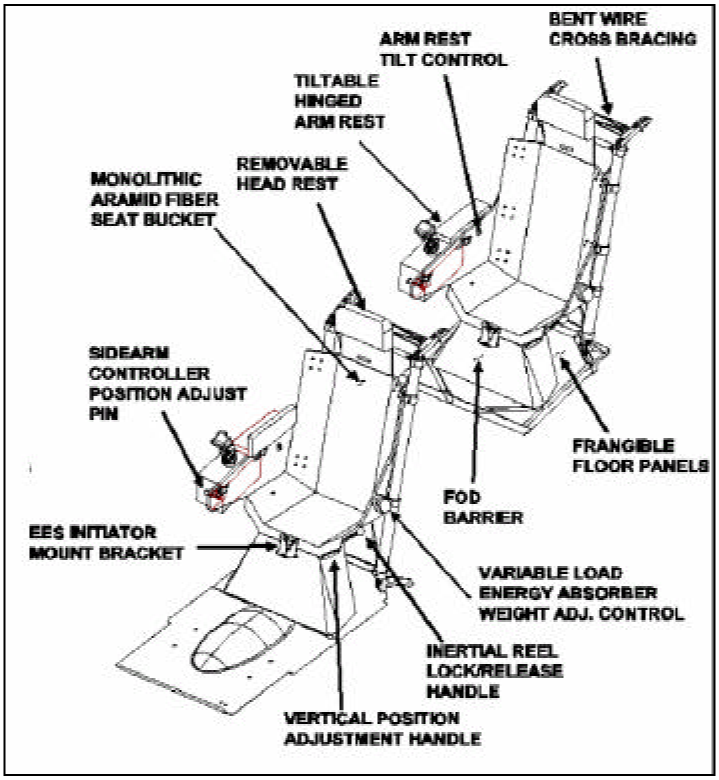


Figure 1. Tandem seating configuration of the Comanche.

Thus, we see that at the intersection of the RAH-66 crew station and the AW ensemble lies a potentially significant human factors problem: can an Army aviator quickly and safely conduct ingress and egress of the crew station while wearing this new AW ensemble?

1.2 Purpose

In response to these concerns, researchers from the U.S. Army Research Laboratory's (ARL's), Human Research and Engineering Directorate evaluated pilot ingress and egress using a RAH-66 Comanche airframe mock-up at Aberdeen Proving Ground (APG), Maryland, and human participants wearing the AW ensemble. The purpose of this evaluation was to 1) assess whether the modified RAH-66 Comanche crew station design supports the requirement for safe and efficient crew ingress and egress during normal and emergency conditions while the crew wears the different AW ensembles, and 2) identify potential solutions for any deficiencies that are encountered for the RAH-66 crew station and the AW ensemble. Several operationally relevant combinations of aircrew anthropometry, aircrew clothing ensembles, and ingress-egress routes were evaluated for the front and rear crew stations.

1.3 Definition of Terms

A comprehensive list of acronyms appears later in this report. However, several terms are defined now since they lie at the heart of the problem statement. These definitions are largely drawn from the U.S. Army Test and Evaluation Command (ATEC) Test Operations Procedure (TOP) 7-3-529 (Department of the Army, 1991), which specifies procedures for testing ingress and emergency egress of Army aircraft. These definitions have some minor modifications that make them specific to the Comanche.

1.3.1 Ingress

Beginning 5 feet from the aircraft, this is the process of entering the crew station, fastening the restraint system, and making all preparations before the aircraft is started in accordance with Technical Manual 1-1520-245-10, chapter 8 (Department of the Army, in press). No specific time criteria are cited in guidance documents. However, emergency egress times may be used as a baseline to compare ingress times and possible significant differences.

1.3.2 Egress

This consists of moving from the crew station in which the participant is seated to the ground. When timed, this is the period from which the seated participant initiates movement out of the mock-up until the time at which both of the participant's feet are in contact with the ground and the participant is no longer in contact with the mock-up.

1.3.3 Normal Versus Emergency Conditions

Tasks performed in "normal" conditions should be executed in a manner that emphasizes the smoothness of performance expected in routine situations. Tasks performed in "emergency" conditions should be executed in a manner that (within the boundaries of safety) emphasizes speed.

1.3.4 Route

This is the path by which a participant can conduct ingress and egress of the mock-up. The normal route is through the left side of the Comanche when the canopy door is open. The left and right window routes are those available in conditions when the pilot has blown the windows from the aircraft.

1.3.5 Emergency Egress

This consists of actions performed by a crew member to quickly and safely leave the aircraft during emergency conditions.

2. Review of Relevant Literature and Research

2.1 Literature Review

The first ingress and egress evaluation of the RAH-66 was conducted on the first prototype aircraft in 1996. Since then, the aircraft underwent significant modifications in the design of the crew station, and the user population that the aircraft must accommodate has grown to include female pilots. The Comanche Program Manager's Office (PMO) at Redstone Arsenal, Alabama, realized the need to re-assess the crew station to ensure safe and efficient ingress and egress by aircrew members. However, a production-representative aircraft was not scheduled to be available for evaluation until late in 2004. Therefore, the Comanche PMO asked ARL to conduct an ingress-egress evaluation using a mock-up that approximates the modified crew stations with a high degree of fidelity.

It is important to properly frame the case for conducting an ingress-egress evaluation in the Comanche (while the crew wears the AW ensemble) with a thorough literature review. There are five primary areas that we must review. First, we must discuss current Department of Defense (DoD) standards for ingress, egress, and emergency egress. Second is a short description of the RAH-66 crew station and the provisions currently designed for ingress and egress, along with any other egress studies performed in the aircraft since it began production in the mid-1990s. Third, a description of the AW system is necessary to gain an appreciation for the many advantages it brings, as well as the disadvantages that remain in bulk and weight. Fourth, we reviewed historical difficulties with ingress and egress from helicopters, particularly tandem seating helicopters. Finally, we reviewed several documents from the developmental and operational testing of AW and a similar system from the U.S. Navy to highlight expected difficulties in our evaluation of the Comanche.

2.2 Current Military Specifications for Ingress, Egress, and Emergency Egress

The primary document that governs ingress and egress procedures for U.S. Army helicopters is from the ATEC TOP 7-3-529 (Department of the Army, 1991). The TOP specifies procedures for testing ingress and emergency egress of Army aircraft. In particular, it specifies several test conditions that are important to highlight (1991):

1. The aircraft configuration to be tested shall be that which most closely resembles the normal operational characteristics of that particular aircraft.

2. Participants must be appropriately attired to reflect the worst case condition during a variety of mission scenarios.

3. Uniforms selected for ingress-egress testing will address the most extreme operational conditions, which is likely a combination of both cold weather and nuclear-biological-chemical (NBC) protective clothing.

4. Representative personnel should be used (as test subjects), who meet the 5th percentile female to the 95th percentile male population (Donelson & Gordon, 1991).

Other provisions in the TOP specify definitions and maneuvers for normal ingress and egress, emergency egress, as well as the test facilities and equipment that must be available.

As for the time standards for ingress and egress, we looked to a series of DoD human factors specifications that have evolved over the past 15 years. Specifically, MIL-STD-1472D, further revised by MIL-STD-1472E, and carried forward to Joint Service Specification Guide (JSSG) 2010-11, states that "emergency evacuation (after crash landing) of crew members shall be possible within 30 seconds" (DoD, 1989, 1996, 1998). For normal ingress and egress trials, the military standards do not specify a time element. However, the TOP points out that times may be compared to emergency egress times in order to "identify existing or potential problems associated with ingress maneuvers" (Department of the Army, 1991).

In addition to the human factors guidance for a 30-second standard, TOP 7-3-529 also acknowledges that "in helicopter crashes with post-crash fires, the available escape time is only 7 to 16 seconds. For a crew to survive under these conditions, they must be able to safely egress the aircraft within 10 seconds (30 seconds for aircraft fitted with crash-resistant fuel tanks). As a result of this short time factor, it becomes imperative that crew members be required to unfasten only their safety harness when emerging from their crew position. Any additional tasks involving manual disconnection from aircraft-mounted equipment shall be considered unacceptable" (Department of the Army, 1991). The current evaluation will focus on the 30-second standard listed in the DoD human factors guidelines.

2.3 The RAH-66 Comanche Crew Station – Ingress-Egress Provisions

The RAH-66 Comanche crew station was designed to be a state-of-the-art human-machine interface designed to allow its aircrew an unparalleled capability to locate, identify, report about, and if necessary, destroy the enemy. The front and rear crew stations employed a series of multipurpose displays in front of each seat for information display and targeting information. In addition, the crew station used a unique set of flight controls, different from its predecessors in the U.S. Army helicopter fleet. The sidearm controller (SAC) replaced the traditional cyclic. It is a four-axis controller, allowing a pilot full pitch, roll, and yaw authority, as well as limited vertical authority. A smaller-than-normal collective allows full vertical lift authority, and two pedals are used for wheel brakes. See figure 2 for a diagram of the crew station (courtesy of Sikorsky Aircraft Corporation).

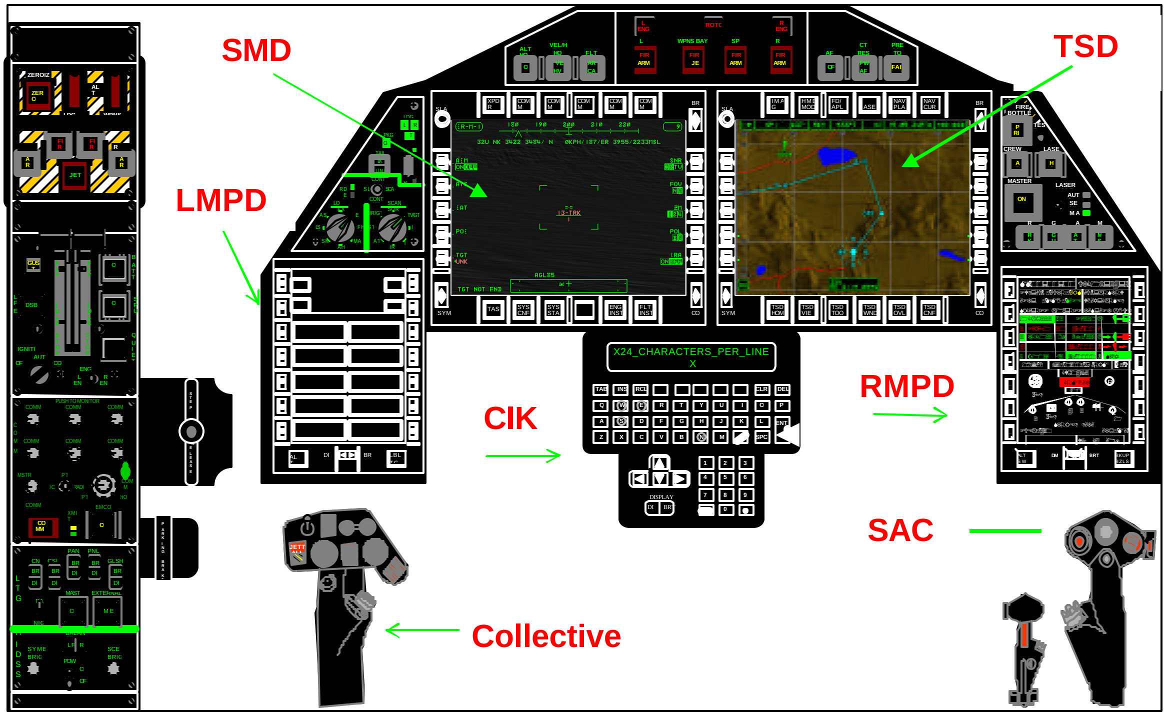


Figure 2. RAH-66 Comanche crew station diagram.

In terms of the areas of the Comanche crew stations germane to ingress and egress, we turn to the aircraft operator's manual (Department of the Army, in press) and figure 2. As discussed in section 1, the crew stations are arranged in tandem with the pilot in the forward crew station and the copilot in the aft crew station. Handholds and retractable steps permit the crew to conduct ingress and egress on the left side of the helicopter. There are hooks on which to place the specialized Comanche helmet optics when they are not in use. In a crash sequence, the retractable landing gear was designed to stroke and then petal to attenuate crash loads as fast as 11.6 meters per second (about 11 g). The crew seats were designed with energy absorbers and frangible[2] floor panels so that the seat will stroke downward in a high-energy crash, providing an additional measure of aircrew survivability. Also, the crew station interactive keyboard (CIK), positioned between the pilot's knees in both the front and rear crew stations, can be folded back underneath the instrument panel relatively quickly to help improve the ingress and egress pathway. So in a normal ingress or egress, both aircrew members enter and leave the crew station from the left side through the canopy doors after stowing the CIK.

For emergency egress of the crew station, several provisions in the crew station and procedures are described in the operator's manual. For emergency situations, the crew may conduct egress through the canopy doors or may jettison the side windows. See figure 3 for a diagram of the emergency escape system (Department of the Army, in press). A grasp "D" ring handle is

[2]Frangibility in the non-lethal community normally describes a part that can be broken easily or in a predetermined manner.

mounted in front of the five-point restraint system center attaching point, below the pilot's legs. The pilot pulls sharply up with a force of 30 lb or greater to activate the window jettison. When he or she does so, all four windows (left and right sides, front and back seats) are released from their frames via a pyrotechnic activator. The location of canopy opening handles and internal jettison equipment is shown in figure 4. The operator's manual directs a number of steps that must occur during an emergency egress and recommends stowing the CIK for an improved exit pathway.

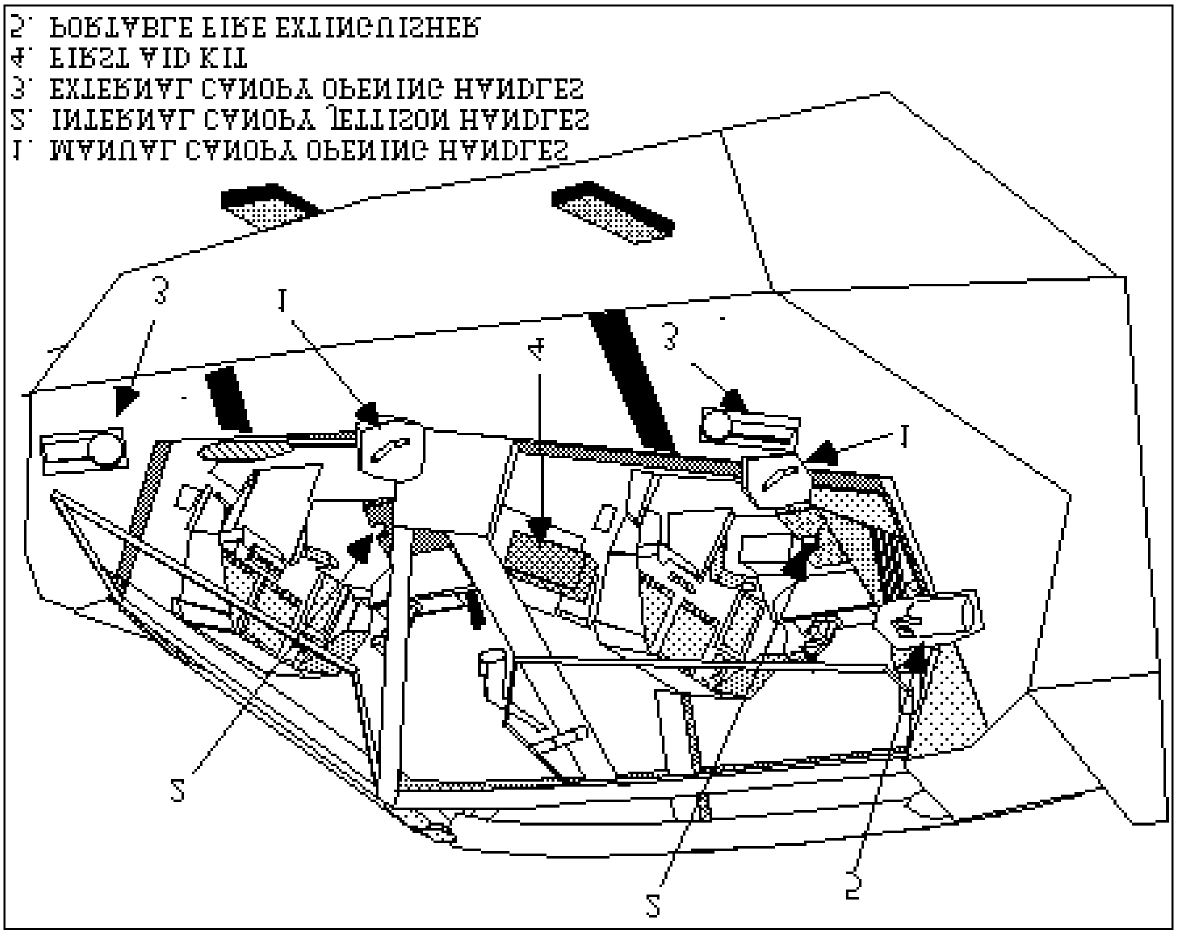


Figure 3. Location of canopy handles and internal jettison handles.

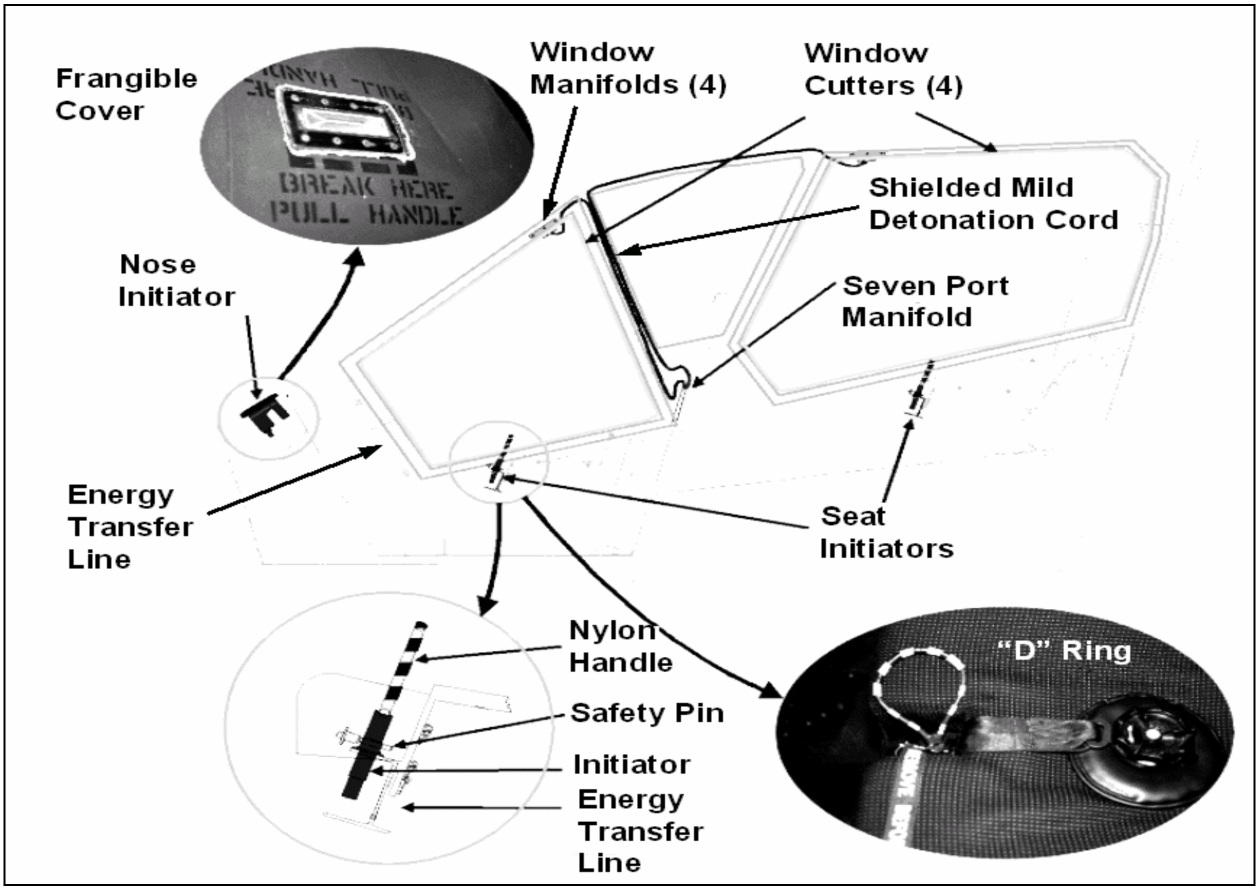


Figure 4. RAH-66 emergency escape system.

2.4 The Air Warrior Aviation Life Support System

The AW ensemble integrates state-of-the-art aircrew mission equipment with personal protective gear and clothing that is primarily aircrew mounted. In the 1990s, user representatives from the U.S. Army Aviation Center (USAAVNC) at Fort Rucker, Alabama, identified an operational requirement for an integrated aircrew ensemble that would reduce weight and bulk, improve aircrew endurance, and improve aircrew mobility compared to then-current ALSE.

As mentioned in section 1, the U.S. Army is pursuing a three-block approach in the development and manufacture of the AW system. Block 1 is directed toward currently available technology. Blocks 2 and 3 focus on the insertion of emerging technology. The AW can be "tailored to support operations in all geographic and environmental conditions against emerging threats. AW system crew-mounted or carried equipment is designed to be with the crew member and readily accessible for use during or immediately following egress from an aircraft that has crashed or executed a forced landing or ditching" (Department of the Army, 2003). The AW system will be fielded to all Army aviation units flying any Army helicopter (Department of the Army, 2001).

ATEC subjected Block 1 AW to a comprehensive testing program during the summer and fall of 2002 and found that it is effective in most current Army helicopters. However, the RAH-66 was not part of the testing since it was still in very early stages of flight testing. Overall, the AW system provides increased personal protection and decreased weight and bulk. See figure 5 for a depiction of the components in Block 1 (Department of the Army, 2003). The blue text in the image represents new equipment in the AW ensemble. The aviator in the image is wearing the standard AW configuration plus the over-water equipment (flotation collar and backpack life raft). Also note that the helmet worn in the image is a normal HGU-56/P, not the specialized Helmet-Integrated Display Sighting System (HIDSS) that was being designed to be worn by RAH-66 aviators.

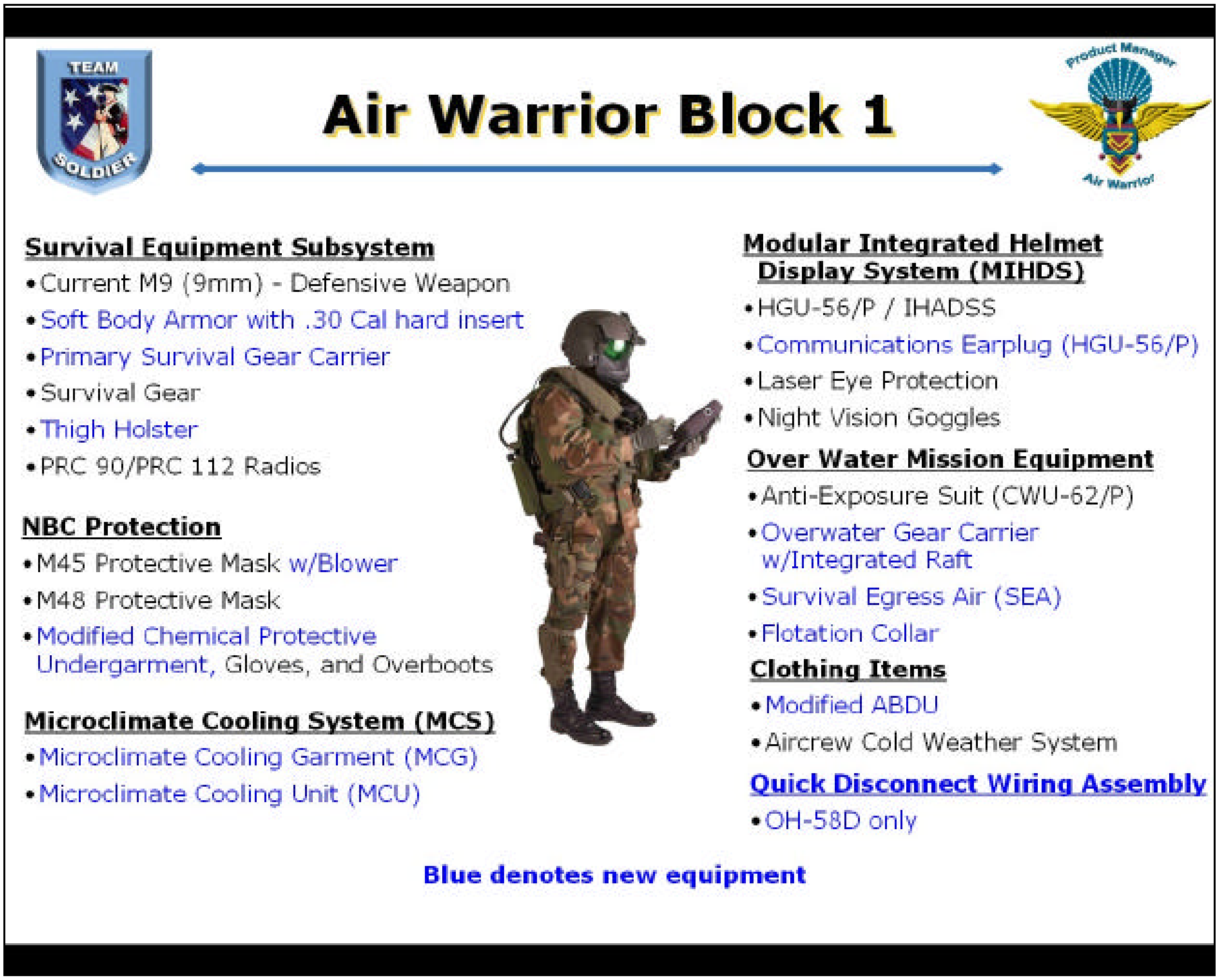


Figure 5. Components of the air warrior block 1.

AW components include a microclimate cooling system (MCS), a survival equipment subsystem, a modular integrated helmet display system (MIHDS), an over-water survival subsystem, NBC protection, and aviation clothing items. The MCS includes a microclimate cooling garment (MCG) that is worn against the pilot’s torso, and a microclimate cooling unit

(MCU) on the aircraft that chills water and pumps it through small tubes embedded in the MCG. The survival equipment subsystem includes a survival gear carrier with integrated extraction harness, ballistic protection vest, 9-mm pistol with thigh holster, hand-held emergency survival radios, and survival knife in ankle sheath. The MIHDS includes laser eye protection and a night vision goggle (NVG) mount. (Note: On the RAH-66, there was no intent to fly with an NVG on the HIDSS.) The over-water survival subsystem includes a low profile personal flotation device, an inflatable raft, and an emergency under-water breathing device. NBC protection includes a modified chemical protective undergarment, an M45 or M48 protective mask, gloves, and overboots. Aviation clothing items include the modified Aviation Battle Dress Uniform (ABDU) and the Aircrew Cold Weather System (Department of the Army, no date).

As depicted in figure 5 and described in the preceding paragraph, one pilot must wear a lot of equipment on his body to conduct a combat mission. The AW system has decreased the bulk and weight that a pilot must wear (as compared to previous ALSE). However, there are still issues in Block 1 with the overall bulk and weight, particularly when a pilot is wearing the body armor, the over-water survival gear, and the NBC protective gear. This fact becomes important when pilots conduct ingress and egress of the crew station, especially if it is an emergency egress.

2.5 Historical Difficulties With Ingress and Egress of Helicopters

The USAAVNC, as well as the other U.S. military services, has long been interested in ingress and egress, particularly emergency egress, among all types of aircraft, fixed wing and rotary wing. The ejection seat built into fighter aircraft is a great example of our yearning to quickly and safely remove a pilot from an inoperable or unstable aircraft. Parachutes are another example of emergency egress equipment. The U.S. Army even conducted a study in 1973 to test a pilot's ability to escape from an auto-rotating helicopter by parachute. Fortunately for the experimental parachutist performing the trials, he found that he could escape even when vertical descent increased to 3,500 feet per minute (Schane, 1974). All the military services have conducted other studies relating to emergency egress, and a review of the National Technical Information Service database revealed approximately 130 technical reports related to emergency egress from the space shuttle. However, our literature review is limited to emergency egress from helicopters since the early 1990s (approximately 15 to 16 reports).

Timothy Swingle (1995) of the U.S. Army Aeromedical Research Laboratory (USAARL) at Fort Rucker conducted a study to survey emergency egress mechanisms for all Army helicopters in the fleet at that time. Some of the items discussed on each aircraft include location and description of canopy jettison mechanisms, direction of opening, size of aperture, and evacuation restrictions. The study outlined the emergency egress measures in two helicopters with tandem seating: the AH-1 Cobra (recently retired from the fleet), and the AH-64A Apache. Unfortunately, the study does not mention possible complications with ALSE, nor does it speculate about any difficulties that might occur with anthropometrically different aviators.

In a related vein, several authors involved with the design of helmet-mounted displays (HMDs), which the Comanche was designed to use, have focused on emergency egress as a design criterion. Other researchers with USAARL listed aircraft egress as a human factors concern when designing HMDs (Rash, 1998; Rash et al., 1999). So we see that when designing for emergency egress, we should focus on the aircraft, ALSE, and helmet design.

The U.S. Navy is also concerned with the ingress and egress from its helicopter fleet. Barker and Bellenkes (1996), both researchers with the Naval Aerospace and Operational Medical Institute at Pensacola Naval Air Station, Florida, conducted a review of the Naval Safety Center database for all U.S. Navy and U.S. Marine Corps (USMC) Class A helicopter mishaps (involving fatalities or more than $1 million in property loss) between 1980 and 1994. They identified and categorized cockpit egress problems reported by pilots and described the data in terms of problem category, helicopter type, crash terrain, and time of day. Of the 210 survivable mishaps, 489 egress problems were reported in 128 (of the 210) mishaps; 61% involved aircrew factors, 16% environmental factors, 12% were related to helicopter factors, and 11% to cockpit factors. Barker and Bellenkes concluded that "egress hazards can be minimized by the implementation of more intensive under-water egress training, crashworthy fuel systems, better design of cockpit exits and hatches, better restraint systems, better crashworthy seats, and more streamlined personal equipment" (1996).

Of particular interest to us are the aircrew (personal clothing and equipment) and crew station factors (seats, restraints, design issues) mentioned in the recommendations from Barker and Bellenkes. The paper discusses the Navy's efforts to combine several current ALSE programs into a more integrated, streamlined ensemble. However, the Navy's focus is on an aircrew surviving a water ditching—a flight profile experienced with lesser focus by the Army. The article confirmed the need for a streamlined ensemble by citing the Army's similar AW effort, although the AW program was in its infancy at the time.

There are two areas of the Barker and Bellenkes paper that bear some scrutiny. One weakness, particularly in regard to the present evaluation of the RAH-66, is the lack of distinction within the H-1 type category. Although they did an excellent job of categorizing egress problems by aircraft type (H-1, H-3, H-46, H-53, etc.), they failed to take into account seating configuration differences in the same helicopter type. Specifically, the Navy and Marine Corps H-1 fleet consists of the AH-1 Cobra (tandem seating) and the UH-1 Huey (side-by-side seating). Experience and common sense show that egress from these two aircraft is very different. Second, for a more thorough and comprehensive review of helicopter egress difficulties, Barker and Bellenkes could have extended their review to the U.S. Army Safety Center's database at Fort Rucker. The U.S. Army has the largest helicopter fleet in the world, and a review of Army mishaps would likely lead to a more comprehensive report. Likewise, the U.S. Air Force maintains a similar database for its fleet, of which, helicopters are a small but important subset.

Another set of researchers for the U.S. Navy performed a human factors safety analysis on the SH-60B Seahawk (Schmidt & Winsko, 1995). Their analysis examined emergency procedures, survival training, crew station design, and protective gear. They argued that system components on the SH-60B meet design and contract specifications but are not optimal or well integrated. "Aircrew egress difficulties include reaching exits, actuating releases, opening hatches, and clearing them" (1995). They also concluded that "anthropometrically extreme aircrew with full flight gear exceed prescribed dimensions and could have problems reaching exits, actuating releases, and/or clearing exits" (1995). They did not define "anthropometrically extreme," but it is safe to assume they meant an aviator near the upper end of the anthropometric range (95th percentile or higher). Their study also points to a limitation of the present assessment in the RAH-66: crew seats that absorb energy by stroking "can inadvertently hinder subsequent egress by modifying aircrew position" (1995). This point is discussed later in the Limitations section.

A final paper of note for past helicopter ingress-egress studies comes from Arthur D. Little, Inc., the firm that helped design the current Air Warrior ensemble. Pensotti, Turieo, Stokes, and Reeps (1998) conducted a study to investigate the feasibility of a seat pack concept as a method for carrying survival gear. Human participant tests were performed with the experimental seat pack in both the UH-60 Blackhawk and AH-64 Apache helicopters. The testing procedure included an assessment of normal ingress and timed emergency egress. Data collection also included anthropometry, photography, and questionnaires. Normal egress procedures were also completed in the UH-60 only. The overall configuration of the subjects' experimental ALSE is fairly close to the AW Block 1. The experimental procedure used by the researchers is well designed, and ideas from this paper were carried forward to the present evaluation in the RAH-66.

For the AH-64, the average emergency egress time was 16.0 seconds with the experimental seat pack and 14.2 seconds with current ALSE. Researchers concluded that the most pervasive problem in the AH-64 was related to chest circumference. Equipment bulk, particularly in the chest region, interfered with reach and egress. Because the published paper was an edited version of a longer (and unavailable) technical report, some details about the exact crew station setup were missing (i.e., were the armor wing panels deployed? How were the cables from the helmet hooked up?). The results from this paper gave us some early indicators of how the production AW Block 1 ensemble will perform during our ingress/egress trials in the RAH-66 Comanche.

2.6 Past Ingress and Egress Evaluations in the RAH-66 Comanche

In the case of the ingress and egress for the Comanche, one of the confounding issues is that further requirements have been thrust upon the aircraft crew station since Sikorsky-Boeing began fabricating prototypes in the early 1990s. Originally, the Army's requirement of the Comanche was that it accommodate a user population with an anthropometric range of 5th to 95th percentile *males*. However, the "total population required to be accommodated within the crew station

increased in 1996 after design of the existing prototype aircraft" (Chase, Copeland, & Ferrell, 2000). The requirement was increased to include the 5th percentile *female* to the 95th percentile *male*. In 2002, the Comanche Operational Requirements Document (2002) was modified to approximately accommodate the 35th percentile female through the 95th percentile male, with the 5th percentile female as a goal. The other emerging requirement relevant to this evaluation is the change in ALSE from current systems to AW. Because pilots will wear the AW ensemble when flying in the RAH-66, an ingress-egress evaluation that includes the AW is necessary.

There have been three ingress-egress evaluations of the Comanche crew stations since the first prototypes were built. The U.S. Army Aviation Technical Test Center (ATTC) conducted the initial assessment with the first prototype aircraft in 1996. Unfortunately, very little documentation exists from this evaluation, and results have been passed mainly by word of mouth. Personnel from ARL conducted an ingress-egress evaluation in 1999; again, documentation from that evaluation is not available.

The most recent emergency egress evaluation took place in May 2003 with one of the prototype aircraft at Sikorsky's West Palm Beach (WPB), FL, facility (D'Louhy, 2003). This well-conducted and well-documented test evaluated a number of conflicts arising from the use of the Comanche-unique HIDSS. Specifically, testers needed to assess whether the HIDSS hindered a pilot during emergency egress and whether a pilot could clear the aircraft in the required 30 seconds. Results from the evaluation showed that three pilots (all Comanche experiment test pilots) were able to conduct egress from the aircraft in an average of 12.9 seconds. Subjective comments were also gathered from the pilots after the emergency egress trials. One particular finding from the pilot commentary regarded their inability to easily move their feet and legs through the small area between the lower glare shield and the collective grip. This finding proved to be a fairly common event in the present evaluation.

The present evaluation expanded on several test conditions that did not exist for the 2003 evaluation in West Palm Beach. First, the experimental test pilots at WPB were wearing another version of ALSE that is not similar to AW (specifically, the AIRSAVE[3] vest). The evaluation did not call for a combat-configured pilot and crew station. Items in AW such as body armor, 9-mm pistol, leg knife, and over-water survival gear were not in use. Several items such as the side armor panels, water canteen, and map cases were not installed on the prototype aircraft. Emergency egress was only conducted out the normal (left) side of the aircraft, since jettisoning the windows would have been very costly. In contrast, the present evaluation used the AW ensemble, side armor panels (that must be retracted by the crew), water canteens, map cases, and other items that will be in the production crew stations. Furthermore, the pilots performed several emergency egress trials out of the right side of the aircraft—a test condition not possible in the flying prototypes because of excessive maintenance costs and air-worthiness considerations.

[3]AIRSAVE is the name of a commercially available product.

2.7 Expected Ingress and Egress Difficulties With Air Warrior Based on Testing

To gain an historical basis for difficulties in the wearing of bulky ALSE in a helicopter, we first turn to an ensemble tested by the U.S. Navy from 1987 to 1990. The A/P22P-9(V) Helicopter Air Crewman Chemical, Biological Protection Ensemble might be called a rough predecessor of the Army's AW. Researchers with the Naval Air Warfare Center at Patuxent River, Maryland, evaluated the ensemble during hot weather ground and flight testing in four USMC helicopter types: the AH-1, UH-1N, CH-46, and CH-53. The primary data collection was physiological and subjective responses from the tested crew members, both pilots and crew chiefs. Ground testing included ingress, egress, and emergency egress in all four aircraft types "to evaluate subjects' ability to get in and out of their crew stations, easily, safely, and quickly" (Bjorn & Huang, 1992). Pilot ingress and egress of the AH-1 were the most challenging because of its "bubble canopy, climb-in, cramped cockpit" (1992). Emergency egress was also evaluated but apparently not timed since no results were reported or discussed. Unfortunately, the report did not include any description of the methodology for the ingress and egress testing. Overall, we see that ingress and egress from helicopters with a focus on ALSE has received emphasis and that a tandem seating configuration presents the biggest problem.

Other researchers from ARL modeled AW during its development to gain an understanding of how the ensemble would affect human performance, both cognitive and physical. Kozycki (1998) argued that, over time, growing burdens from a pilot's ALSE have begun to severely degrade helicopter operator performance. Kozycki described an approach to assess the operational impact of AW using three-dimensional (3-D) graphical anthropometric human figure models fitted with digitized ALSE in a software program called Jack[4]. This method of 3-D human figure modeling minimizes the need for an actual aircraft or physical mock-up early in the design process. This is particularly important in the case of the RAH-66 since only two prototypes are available, and access to these is very limited. See figure 6 for a recent example of the AW ensemble applied to human figure model in Jack.

Another paper from researchers at ARL further describes 3-D human figure modeling with the AW ensemble, as well as work with a human workload model to understand the ensemble's effect on aviator performance (Harrah, Kozycki, Salvi, Tauson, & Kehring, 2001). Analyses from this paper show that in terms of a particular AW configuration, the condition when a pilot is wearing chemical-biological protective and over-water survival gear simultaneously (NBC-OW) represents the worst case in terms of reach restriction. This provides a literature basis, in addition to our own common sense, for the hypothesis that certain AW configurations will degrade emergency egress performance. The paper also describes an early motion-capture video system that was used to obtain range of motion data from the subjects' upper body for input to the human figure models. A newer motion-capture system from the U.S. Army Tank-Automotive Command

[4]Jack is a trademark of Unigraphics, Inc.

(TACOM) was employed in the present Comanche evaluation to obtain further validation of this new technology.

Figure 6. Example of digitized AW ensemble on 3-D human figure model.

Another paper from Pensotti, Berube, Bucher, Dart, Dunfey, and Turieo (1999) describes a "systems approach for designing the physical architecture" of the AW to produce acceptable human performance. They reasoned that an aviator's ability to fly and fight can be "enhanced by integrating human performance with technical and equipment requirements" (1999). Further, they argued that human performance (not equipment performance) is the best measure of success.

Like the studies from ARL, this paper points to human anthropometric and AW conditions that will represent the worst case in terms of performance. In their study, the 95th percentile male represents the worst in terms of clearance, limited control movement, and volume associated with the ensemble's interface to the aircraft. In addition, the 5th percentile female represents the worst case scenario in terms of available surface area to mount equipment on the AW clothing. Also of note are their findings regarding the AH-64 Apache. Their evaluation identified the

Apache as a problem for wear and use of the AW. The Apache has a tandem seating configuration that is very similar to Comanche's. So, in 1999, researchers knew that there would be problems with the AW in a tandem seating helicopter.

The final literature source to be considered is the 2002 ATEC system evaluation report (SER) for the AW Block 1 operational test conducted in 2002 by ATEC. AW was tested in four current Army helicopters: UH-60, OH-58D, CH-47D, and AH-64D. An important criterion in the test reads, "AW will not reduce or degrade the aircrew members' movement, comfort, field of vision, ability to reach controls, ingress, or egress, including emergency egress, as compared with current mission/survival equipment" (Department of the Army, 2003).

The report found that ingress and egress were adversely affected by the bulk of the AW ensemble. Although pilots wearing non-combat configurations fit easily into crew stations, inclusion of combat equipment (e.g., body armor, pistol) presents issues of crew station limitations and flight control interference. To avoid similar compatibility issues, current and future aircraft design programs must make crew stations large enough to accommodate crew members from the 5th percentile female to the 95th percentile male wearing the bulkiest AW configurations.

The results from the emergency egress testing performed on the AW are very important in application to the present evaluation in the Comanche but show a real contradiction in terms of subjects' ability to conduct egress from an aircraft during an emergency in less than 30 seconds. According to the report, during early developmental testing (DT) with experimental test pilots, "all four aircraft demonstrated that all AW test configurations allowed…crew members to successfully accomplish normal ingress and emergency egress; *however, armor side panels were not installed during DT trials"* (2003) (emphasis added). All DT emergency egress trials were completed within 30 seconds. However, testers found that normal ingress was awkward because of the bulk of the system which could cause unintentional input to the flight controls. Despite this finding, they concluded that "Air Warrior is considered effective in aircrew ingress and egress" (2003).

However, in later operational testing (OT) with line Army aviators, emergency egress testing was only planned for the UH-60. Testers found the average time to egress was 17 seconds with armor side panels installed. No emergency egress trials were planned or conducted in the AH-64D and OH-58D. CH-47D test subjects "expressed concerns over their ability to safely egress the aircraft" (2003) in the bulkier AW configurations, so a limited number of emergency egress trials were conducted. Half of the trials (8 of 16) confirmed that it is extremely difficult for subjects wearing the over-water survival gear to leave the CH-47D through the crew station doors with the side armor panels installed. *The average time to leave with the panels in place was **50** seconds* (emphasis added). Despite these findings, testers concluded that there are "no significant differences in aircraft or ensemble configuration that would affect the results" (2003).

The conclusions reached in the AW SER in terms of emergency egress are of considerable note since they seem to contradict the test results of the CH-47D. Of course, it would have been preferable to conduct emergency egress trials in OT with a combat-configured pilot in an AH-64 with side armor panels to ascertain how long it would take him or her to leave that aircraft during an emergency. However, the difference in results between DT, OT in the UH-60, and OT in the CH-47 tells us that a pilot in combat AW ensemble sitting in a combat-configured crew station (especially a tandem seating crew station) may not be able to meet the 30-second standard from military specifications for emergency egress.

3. Method

3.1 Participants

Two male and two female pilots were recruited as participants. Each pilot was selected on the basis of how closely he or she approximated the anthropometric characteristics of a large male (approximately 95th percentile), a medium male (approximately 50th percentile), a medium female (approximately 50th percentile), or a small female (approximately 5th percentile). The reference for anthropometry is the U.S. Army's 1988 anthropometric survey of pilots by Donelson and Gordon (1991). See appendix A for a table of target anthropometric values for each subject.

All four participants were rated Army aviators. One male participant was assigned to the Training and Doctrine Command System Manager–Comanche (TSM-C) office at Fort Rucker, and the other male participant was assigned to the TSM-C office in Philadelphia, Pennsylvania. Both males held the rank of Chief Warrant Officer 4 and were rated as instructor pilots in the AH-64A and AH-64D. The medium female subject held the rank of Warrant Officer 1 and was a student pilot in the OH-58D track of the Army's Flight School XXI. The small female held the rank of Captain and was rated as an instructor pilot in the AH-64A. The relevant demographic characteristics of the pilots are listed in table 1. No participant was on a temporary or physical medical profile, nor did any participant report any physical limitations. See figure 7 for a photo of the four participants.

Table 1. Pilot demographics.

Summary of demographic characteristics	Age (yrs)	Total flight hours in Army aircraft
Mean	37	1698
Median	33	1851
Range	29-53	90 to 3000

The participants were briefed about the purpose of the evaluation and their volunteer rights and were asked to sign a volunteer agreement affidavit (appendix B) before any further processing

was done. The participants were then measured by ARL personnel to determine if they approximated the anthropometric characteristics of a large or medium male or medium or small female. A female employee from the USAAVNC Field Element was present to observe and help measure potential female participants.

Figure 7. Four participants in order of anthopometric size.

The following measurements were obtained for each potential participant:

- Stature
- Weight
- Buttock-knee length
- Sitting height
- Acromion height, sitting
- Biacromial breadth
- Bideltoid breadth
- Crotch height
- Popliteal height
- Functional grip reach, extended
- Chest depth
- Hip breadth
- Shoulder circumference

The participants were then given a copy of the ingress-egress evaluation plan and a copy of the volunteer agreement affidavit. This provided them with additional information about the scope of the evaluation and the tasks they would be asked to perform. Once they reported for the study at APG, all participants completed a more thorough set of anthropometric measurements. These measurements were used to construct the 3-D human figure models of each participant in Jack. See appendix C for each participant's actual anthropometric measurements.

3.2 Research Design

The formal evaluation was conducted during a 5-day period in July 2003. The first day (Day 0) was a travel day for most participants. Initial briefings, training, rehearsals, and data collection setup occurred on day 1. Formal trials were conducted over a 2-day period on days 2 and 3. The final day (day 4) was used for return travel and initial data review and reduction by the investigators.

The evaluation included four different independent variables (IV): aircrew anthropometry, emergency egress direction, AW ensemble, and crew station. The dependent variable (DV) was the time to complete ingress or egress of the crew station. We used a within-subjects design with each participant completing a total of 20 trials over a number of different conditions (see table 2). Eight of the trials were during normal ingress and egress; the remaining 12 were emergency egress trials. In addition, the evaluation was qualitative in nature as each subject was asked for his or her feedback about the limitations of the crew station and the AW ensembles during ingress and egress. See appendix D for the questionnaires that were administered.

Table 2. Task conditions.

Trial	Task	AW Configuration	Route	Condition	Crew Station
1	Ingress	Combat - Hot	Normal (Left)	Normal	Front
2	Egress	Combat - Hot	Normal (Left)	Normal	Front
3	Egress	Combat - Hot	Normal (Left)	Emergency	Front
4	Egress	Combat - Hot	Left Window	Emergency	Front
5	Egress	Combat - Hot	Right Window	Emergency	Front
6	Ingress	Combat - Hot	Normal (Left)	Normal	Rear
7	Egress	Combat - Hot	Normal (Left)	Normal	Rear
8	Egress	Combat - Hot	Normal (Left)	Emergency	Rear
9	Egress	Combat - Hot	Left Window	Emergency	Rear
10	Egress	Combat - Hot	Right Window	Emergency	Rear
11	Ingress	MOPP IV - OW	Normal (Left)	Normal	Front
12	Egress	MOPP IV - OW	Normal (Left)	Normal	Front
13	Egress	MOPP IV - OW	Normal (Left)	Emergency	Front
14	Egress	MOPP IV - OW	Left Window	Emergency	Front
15	Egress	MOPP IV - OW	Right Window	Emergency	Front
16	Ingress	MOPP IV - OW	Normal (Left)	Normal	Rear
17	Egress	MOPP IV - OW	Normal (Left)	Normal	Rear
18	Egress	MOPP IV - OW	Normal (Left)	Emergency	Rear
19	Egress	MOPP IV - OW	Left Window	Emergency	Rear
20	Egress	MOPP IV - OW	Right Window	Emergency	Rear

MOPP = mission-oriented protective posture

As can be seen from table 2, each subject completed a normal ingress and egress of each crew station (front and rear) in two separate AW configurations. These trials were not during emergency conditions and were timed for general information about how long it takes to conduct a normal ingress and egress. The main results from the normal ingress-egress trials were the questionnaire feedback that each subject gave after the trial as well as observations from the investigators. In addition to the normal ingress-egress trials, each subject completed three emergency egress trials from each crew station (front and rear) in two separate AW configurations. A videographer was available to record video and take still photos throughout the evaluation, and those proved to be a valuable addition to the qualitative data.

A number of personnel associated with ARL, the Comanche PMO, the AW PMO, and Sikorsky Aircraft Company (among others) were present during the evaluation for specific subject matter expertise. An AW life support equipment specialist was present to assist in the use of the AW equipment. From Sikorsky, the lead crew station engineer advised us about exact layout of the real Comanche crew station. Also from Sikorsky was the primary engineer for the Comanche helmet (HIDSS) for fitting expertise. Personnel from several other U.S. Army agencies (particularly those involved in test and evaluation) and Sikorsky Aircraft Company were on site to observe the evaluation and to lend subject matter expertise as needed.

In addition to the gear already mentioned, several other items were required to conduct the evaluation, which included

- Video recording equipment
- Digital stopwatches
- AW ensembles (see figure 5)
- HIDSS prototype and cabling
- Large bag anthropometric measuring kit
- Cushioned mats
- CorTemp2000 ambulatory recorder
- CorTemp temperature sensors (pills)
- WiBGeT RSS-214 heat stress monitor
- Tape measure
- Maintenance platform to elevate photographic and data collection personnel
- Cushioned area for test participants to land on when conducting emergency egress trials

3.2.1 Procedures and Participant Scenario

On day 1, the participants received a briefing about the purpose of the evaluation and were allowed to see the equipment. The investigative team then administered an informal evaluation to ensure subjects were not limited by physical or range-of-motion difficulties. Subject matter

experts (SMEs) from the AW PMO at Redstone Arsenal fitted them with the AW ensembles. The participants then signed a second volunteer agreement affidavit before actual participation. Before data collection began, participants were allowed to familiarize themselves with the layout of the Comanche mock-up and were trained in proper ingress and egress techniques. Practice periods occurred before the beginning of the evaluation trials. Practice periods also occurred when the participants donned a new clothing ensemble (e.g., MOPP-OW ensemble). Before and after each trial, the AW SMEs assisted the participants in donning and doffing the AW ensemble. Each participant performed the ingress and egress tasks in the manner described below. See appendix E for a checklist of the actions that occurred.

To standardize the seated position for each participant, investigators placed each participant on his or her design eye line (DEL). When placed at their DEL, participants had approximately a 17.5-degree "look-down" angle over the glare shield. The location of each subject's seated eye line was determined through the use of a Faro[5] Bronze Arm, a portable coordinate measuring machine (CMM) with an accuracy of 0.30 mm. The Faro Bronze Arm is a 6-degree-of-freedom arm that can be used to locate 3-D coordinate points in space or digitize the surface of complex 3-D curvilinear objects. It has an operating hemispheric envelope of approximately 8 feet. Each of the six joints on the arm has a hybrid analog-digital rotary transducer to keep track of the rotation at each joint as the arm is moved through space. The signals from these transducers are sent via serial cable to a serial controller box and from there to a computer through another serial line. All the information gathered from the transducers is resolved into coordinate values for the location of the tip of the arm, which contains a probe for measurement of objects. Participants sat in each crew station while the investigators adjusted their seat position to put them on their DEL. Those seat positions were recorded so that they could be duplicated later as the participants completed record trials. SMEs from Sikorsky assisted ARL personnel in making these adjustments and confirming proper location of the DEP for each subject.

Each trial began with the participant standing 5 feet from the mock-up. The primary investigator (P.I.) loudly announced information about the conditions of the trial (e.g., participant number, front or rear crew station, type of AW ensemble) and then announced the word "go". Timing began, and the participant opened the canopy door, entered the mock-up, closed the canopy door, fastened the restraint harness, donned the flight helmet, connected the HIDSS cable, put hands and feet on the flight controls, completed all steps included in the ingress checklist (see appendix E), and gave a "thumbs-up" sign to the P.I. When the participant gave the thumbs-up sign, timing ceased. After timing ceased, the participants were asked to demonstrate that they could reach and view the crew station controls and displays and have adequate visibility over the nose of the mock-up. A post-trial questionnaire was then administered to the participants.

Normal egress trials began with the participant seated in the mock-up and the restraint harness fastened. The HIDSS cable and MCU cable were connected and the participants placed their

[5]Faro Technologies (www.faro.com)

hands on the flight controls and their feet on the pedals. The CIK was in the deployed (non-stowed) position and the canopy door closed. At the start signal ("go" plus hand signal), timing began and the participant unfastened the restraint harness and the HIDSS cable, stowed the CIK, and exited the mock-up at a comfortable pace. Timing ceased when the participant reached the ground and was no longer in contact with the mock-up. A post-trial questionnaire was then administered to the participants.

Emergency egress trials also began with the participant seated in the mock-up and the restraint harness fastened. The HIDSS cable was connected and the participants placed their hands on the flight controls and their feet on the pedals. The CIK was in the deployed (non-stowed) position and the canopy door closed. At the start signal ("go" plus hand signal), timing began and the participant unfastened the restraint harness and the HIDSS cable and exited the mock-up as quickly as possible in accordance with the checklist in appendix E. Timing ceased when the participant reached the ground and was no longer in contact with the mock-up. Again, a post-trial questionnaire was administered.

If participants or evaluation personnel noted a problem in the performance of any task, adequate time was taken to closely examine the problem and determine potential corrective design or procedural measures. In one case, a corrective procedural measure was identified and an additional trial performed. If the participant encountered a safety problem for any reason during the trial, that trial was halted immediately to ensure safety of the participant. If necessary, the trial was repeated.

To minimize fatigue, after each emergency egress trial, the participants were given an opportunity to sit, rest, and drink water if desired. For ingress-egress tasks that required the participants to be attired in the MOPP-OW configuration, each participant performed only one ingress-egress task sequence before taking a break. As a minimum, participants took rest breaks every 30 minutes. The rest breaks typically lasted 5 to 10 minutes. Additional rest breaks were taken when deemed necessary by the P.I. and associate investigators or at the request of participants.

Videotaping equipment was used throughout the evaluation to obtain a permanent record. Ambient temperature readings were monitored continuously and recorded on the post-trial questionnaire for each trial. The P.I. and associate investigators recorded any problems experienced by participants during the trials on the post-trial questionnaire. Comments made by participants during the trials were also documented on the post-trial questionnaires. After the completion of trials for each clothing ensemble (Combat-Hot, MOPP-OW), participants completed an end-of-phase questionnaire to obtain additional recommendation, comments and feedback (see appendix D).

3.2.2 Safety Precautions

Although ecological and external validity were key aspects of this evaluation, there was also a considerable safety emphasis to ensure the health and welfare of the four participants. No evaluation is worth an injured participant. Conducting an emergency egress from the aircraft (especially the rear crew station) involves a considerable drop to the ground with the possibility of cables or clothing getting caught on the airframe, possibly causing serious injury to the aviator. Accordingly, in some trials, we sacrificed ecological validity for safety in instances when doing so ensured the health and welfare of the participants.

Several safety measures were in place during the conduct of the evaluation. First and foremost, at least two (sometimes three) spotters were next to the aircraft during all trials to assist, even support, the participants if necessary for safety reasons. However, the spotters did not support the weight of a participant unless injury was imminent. Mats were placed around the mock-up to minimize injuries to participants if they fell during the trials. A 12- by 10-foot mass of foam blocks, enclosed in a Tyvek[6] protective cover, was positioned underneath the appropriate side for emergency egress trials. See figure 8 for an image of some of the safety matting used.

Figure 8. Comanche structural test article (STA) mock-up. (Note the foam mats and Tyvek bag for safety.)

Heat stress was also a concern since the evaluation was conducted during the middle of summer. There were two fully functioning air conditioning units in the open bay where the evaluation took place. These air conditioners kept the ambient air temperature well below 75 °F at all times. The temperature ranged from 61.9 °F to 70.4 °F, with a mean of 64.5 °F. A heavy duty fan was used in the facility during the trials to provide cooling for participants. A WiBGeT RSS-214 heat stress monitor continuously recorded ambient temperatures during the entire evaluation. If the ambient

[6]Tyvek is a registered trademark of DuPont (www.tyvek.com).

temperature heat index had equaled or exceeded 85 °F (29.4 °C) during trials when participants were wearing the combat-hot configuration, the evaluation would have been halted. The evaluation would not have resumed until the heat index fell below 85 °F (29.4 °C). If the ambient temperature heat index had equaled or exceeded 75 °F (23.8 °C) during trials when participants were wearing the MOPP-OW configuration, the evaluation would have been halted. The evaluation would not have resumed until the heat index fell below 75 °F (23.8 °C). None of the participants volunteered to participate in an additional individual monitoring precaution, which was to swallow a disposable CorTemp[7] telemetry sensor. Core body temperature would have been monitored every 5 minutes. If any participant had exceeded a core body temperature of 102.7 °F (39.3 °C), he or she would have been immediately removed from the evaluation for the day. Fluids in the form of water and Gatorade[8] were available at all times for the participants to drink. They were encouraged to drink to satisfaction to prevent dehydration.

3.3 Methods of Data Collection

There were three sources of data collection for the evaluation. First, each trial was timed via digital stopwatch. Second, the questionnaires (see appendix D) provided subjective and expert observational data to complement the timed data. Finally, the ARL videographer recorded the entire evaluation on video and still photography (both film and digital). The video and photographic record of the evaluation provided valuable backup material to underscore any major observations or findings from the participants or investigators.

3.3.1 Data-Gathering Device

The evaluation was conducted with a refurbished RAH-66 Comanche STA mock-up at APG. The STA mock-up is an actual airframe built by the Sikorsky Aircraft Corporation at their Bridgeport, Connecticut, facility—one of three fabricated in the early 1990s. Two became the flying prototypes that conducted flight testing at the Sikorsky facility near West Palm Beach. The other went to APG for live fire and environmental testing. The U.S. Army Aviation Logistics Schools (USAALS) took possession of the airframe after it completed testing. USAALS then loaned the airframe to ARL for the purpose of conducting the ingress-egress evaluation. The STA mock-up is simply an airframe: no engines, rotor blades, avionics, tail boom, landing gear or tail rotor. ARL refurbished the interior with crew seats, replicated flight controls, display panels, and interior stowage compartments to make the crew station as production-representative as possible. The Faro arm provided accurate locations for the components and equipment that were installed in the mock-up. The Faro arm was also used as a quality assurance device to maintain adherence to location tolerances of all interior components and equipment. See figure 8 for a photograph of the STA mockup.

---

[7]CorTemp is a registered trademark of HQ, Inc. (www.hqinc.net).
[8]Gatorade is a registered trademark of the Gatorade Company.

As mentioned previously, we used a pair of post-trial and post-evaluation questionnaires to gain expert feedback and comments from the participants as the evaluation progressed. These questionnaire instruments were developed in accordance with published guidelines for proper format and content (O'Brien & Charlton, 1996; Babbitt & Nystrom, 1989a, 1989b). A pre-test was conducted to refine the questionnaires and to ensure that they could be easily understood and completed by the participants.

3.4 Pilot Study

The investigative team conducted a pilot study in the STA on 4 and 5 June 2003 at APG, with the first and second authors acting as participants (not the actual aviators from the record evaluation). Over the course of 2 days, the team completed a lengthy series of ingress and egress trials. The trials were conducted during normal and emergency conditions, with multiple variations of the AW ensembles, from both front and rear crew stations, and out both sides of the aircraft. The ARL videographer was also present to take still and video images of all trials for historical and references purposes, as well as rehearse for the record evaluation.

The investigative team put into place and rehearsed all planned safety measures for the evaluation. Representatives from the Comanche PMO and Sikorsky were present to observe and comment on the mock-up and evaluation plan. Especially important was the presence of the lead crew station engineer from Sikorsky to validate the fabrication of all crew station components and ensure that the mock-up was production representative.

The investigative team used the initial trials for training and familiarization with the Comanche and the AW ensembles. Trials were generally timed for informational purposes to give us an idea of the length of time necessary to conduct normal ingress and egress. As might be expected with a cramped crew station such as the Comanche, each aviator has to go through a learning phase to find the most efficient way of entering and leaving the aircraft safely and efficiently. Lessons learned in this area were explained to the participants before record trials. For example, we found it more efficient to rest the flight helmet on top of the sidearm controller while getting in and out. Also, during emergency egress from either side, we found it faster to leave the aircraft face out (torso away from the aircraft) instead of the face-in direction used for normal ingress and egress.

The investigative team developed detailed checklists for ingress, egress, and emergency egress before conducting the pilot study. Steps in these checklists represented all the individual steps that the investigators and pilots accomplished during the trials. These checklists were further refined and amplified from the results of the pre-trials, and the versions used in the record evaluation are given in appendix E.

3.5 Human Figure Modeling and Motion Capture

3.5.1 Human Figure Modeling

The use of human figure modeling has gained widespread acceptance over the past two decades, particularly in the application of workplace design. It has proved to be an effective tool for evaluating the human-in-the-loop interaction between the operator and the crew station. In fact, Comanche has used human figure modeling software to examine several aspects of the program (Kozycki, 2002). Some of these past uses include evaluating the crew station design to determine the extent of modifications needed to meet the population accommodation requirement as well as to examine pilot body postures that could produce helmet strikes to the adjacent canopy frame structure when the HIDSS is worn. Other uses include exploring placement of added crew station components and simulating over-the-nose vision for the pilot.

Jack was also used for this study to help examine pilot ingress and egress. The Jack software is an interactive tool for modeling, manipulating, and analyzing human and other 3-D articulated geometric figures (Badler, Phillips, & Webber 1993). The software contains a utility for importing anthropometric data that are used to build and size the human figure models. This aspect of the software allows the human factors analyst to tailor the models to represent a specific user population for whom the equipment design is targeted.

Video and still photography cameras were employed for this study in order to help document the results and spot problems. However, in order to further augment this study, it was decided that human figure modeling combined with motion capture data could help to analyze the bio-mechanics of the pilots performing ingress and egress of the Comanche crew stations. The motion capture equipment used for this study was owned and operated by the U.S. Army Tank-Automotive Command (TACOM).

3.5.2 Motion Capture System

Motion capture is a combined hardware and software environment focused specifically on capturing complex motion (i.e., human) and then generating digital traces or paths that can then be used to animate digital avatars or humans for the purpose of analysis, simulation, and training. The system used by TACOM is a Vicon optical motion capture system, with the following capabilities:

- 16 camera system (10 large infrared cameras for large areas, and 6 lipstick-miniature infrared cameras for small or enclosed volumes)
- Capture rate of 60 Hz or 60 frames per second
- Tracking capability for as many as 100 independent optical markers
- 64-channel analog capture board

- Real-time motion capture engine (capability to animate a digital avatar simultaneously with the motion capture session)
- Suite of software tools used to post-process and animate the motion data.

Motion capture work was previously done and developed for the entertainment industry where complex or impossible scenes were developed digitally with high-powered computers and graphic engines. The reason for using motion capture was that complex human motions when developed by a programmer or animator for computer-generated characters had an unnatural or unrealistic appearance. In order to "sell" the audience on the story, other approaches had to be developed to generate human motion. Most of today's feature length computer-generated animated movies as well as gaming software with computer-generated characters now routinely incorporate motion capture data to make the movements of the character appear very life-like. TACOM began investigating motion capture technology in 1997 as a tool that could be used in the field of human factors and ergonomics. A shared collaboration between the TACOM and the former General Motors (GM) Delphi (now Delphi Automotive Systems) proved that human motion data could be captured and could prove valuable in the analysis, simulation, and improved training development for new and existing systems.

The benefit of using motion capture equipment is that it provides the ability to capture the action or activity and view the motion from an infinite number of angles. The human factors engineer can then select the ideal perspective that best conveys or represents the problem he or she is trying to analyze as opposed to traditional video or still image photography where the motion can only be viewed from only one angle. The motion capture data, when combined with human figure modeling, represent the actual posture and procedure used by a human subject performing the task and not some subjective motion sequence developed by a programmer or animator sitting at a keyboard. The thought here is that you are evaluating the actual human performance and not an idealistic animation of that human figure model.

This capability also provides a couple of inherent benefits not apparent to the target audience. For example, if the participant is an expert in the task being accomplished, you are actually capturing this expert's approach and technique in accomplishing the task. Individuals can then play the animation developed from these data for training purposes or compare techniques to achieve optimal performance such as professional and olympic athletes. Another benefit that results from the accuracy of the data is that you can evaluate posture over time to determine detrimental changes in posture (i.e., slouching, changes in approach and technique), which can be used to evaluate fatigue levels. This can also be used to determine recovery time through the reversal of this process.

The combination of the videotape and motion capture records has other possible analytical uses in the future if time and need dictate. These include (personal communication, Dr. Mary Ann Valk, March 2004)

- Enables one to view system's processes repeatedly;
- Provides a permanent and broadly distributed data record;
- Can be easily stopped, started, and reversed for repeated observation in slow, normal, and fast motion;
- Provides a built-in process for recording time tags along with the video;
- Serves as a training aid that can be methodically evaluated;
- Shows excessive task times for ingress and egress, revealing human errors and identifying improper procedures.

3.5.3 Motion Capture Equipment

The following equipment and software was used in the Comanche ingress-egress study:

- 10 standard infrared cameras for large volumes, 640- by 480-pixel resolution, and six lipstick-miniature cameras, 320- by 237-pixel resolution for small or enclosed volumes.
- One data station for synchronizing all the camera data, which sends these data to the motion capture workstation for processing.
- One workstation, 2.5-MHz Pentium 4 processor, used to convert the two-dimensional TVD data into 3-D virtual space.
- Software: Vicon Workstation for motion capturing and Vicon Bodybuilder for motion editing and animation.

3.5.4 Markers

In general, three optical markers were placed on each limb of the subject at the proximal, distal, and middle locations of each limb with a focus on eliminating symmetry. Four markers were used on each subject's head, with two attached to the anterior side and two on the posterior side. For the upper torso, markers were attached at the seventh cervical vertebrae and tenth thoracic vertebrae locations as well as above the right and left acromion, the clavical, and the suprasternale body landmarks. Four markers were used on the pelvis, with two on the anterior side and two on the posterior side. Markers were placed on the legs in similar fashion to those placed on the arms, again focusing on eliminating symmetry. Each foot has markers on the ankle, heel, toe, and at the fifth metatarsophatangeal joint location. On average, 38 to 44 markers are required to capture the full motion of a human subject. For this evaluation, 39 markers were used on each subject. See figure 9 for an example of the large male (95th percentile) wearing the markers.

For most applications, a motion capture is usually performed with a subject wearing a thin spandex-type body suit so that the markers can be attached as closely as possible to the body surface landmarks. However, a key element of this evaluation was the AW ensemble. The bulky ensemble made attachment of the markers difficult. To compensate for the clothing, the

markers were attached to the participants with tape and elastic bands to keep them as close to the body as possible. The foot markers had to be taped onto the boots near the foot landmarks. For the head, the markers had to be attached to the HIDSS instead. Another problem encountered with markers was that some of them frequently became dislodged from their attachment points as the participants came into contact with crew station components or canopy frame structure during trials (especially emergency egress trials).

Figure 9. Large male wearing the motion capture body markers.

3.5.5 Camera Placement

Cameras were placed to provide as much double coverage of a region as possible since the motion capture system requires two cameras to see a marker before it will calculate a position in space. Having more cameras that can see a marker improves the accuracy of the data from a standpoint of position and labeling.

The most challenging problem with collecting motion capture data for this evaluation was the obscuration of the markers to the cameras. Most motion capture applications usually take place in an open, unobstructed environment. For this evaluation, the Comanche crew station components, canopy frame structure, safety spotters, and even the safety mats often obscured the markers from the cameras, especially those markers on the lower extremities. The standard infrared cameras were set up on tripod mounts elevated approximately 10 feet off the ground in order to gain optimal exposure to the markers (see figure 10).

Figure 10. Placement of the infrared motion capture cameras around the STA.

3.5.6 Marker Data

Before the marker data could be imported into the Jack software, a "scrub" of the raw data had to be performed because of several problems encountered. The first problem with the data appeared in the form of "ghost" markers. These were false marker data points that were produced from initial and secondary reflections from the canopy windscreens. These ghost marker data points had to be identified and separated from the actual marker data points. In most cases, these points could be identified because of the stationary position of the marker points; however, some of these points were attributable to secondary reflections from the markers themselves and therefore were more difficult to sort. Another problem came in the form of data "drop-outs" that were attributable to (a) obscuration of a marker so that it was not visible to at least two cameras at some point in the motion capture sequence or (b) the marker which had become dislodged from its mounting point. "Virtual" marker data points could in many cases be developed to replace the actual marker data points lost to drop-outs if data from two adjacent marker points were available at that instance in time. This adjustment of the marker data proved to be a slow and time-consuming stage of the motion capture process.

3.5.7 Collection of Pilot Anthropometric Data

In order for the human figure models to play the motion capture data correctly, a human figure model for each of the four participants had to be created and sized to accurately reflect each

subject's body anthropometry. This required 53 additional body measurements to be taken on each participant for the purpose of creating each human figure model. The specific body measurements taken, which are listed in appendix C, were obtained with a standard anthropometry kit and were taken in accordance with the methods and body landmarks described in Gordon et al. (1989).

3.5.8 Importing Motion Capture Data Into Jack

Once the motion capture data were imported into the Jack software, each marker location could then be constrained to the corresponding location on the matching human figure model for that participant. The marker locations were revised every 1/60th of a second throughout the entire motion sequence, except for data drop-outs because of marker obscurations or lost markers. These data points thus controlled the movements of the human figure body segments and reproduced the motions of the subject for whom the motion capture data were collected.

3.6 Limitations of Assessment

3.6.1 STA Limitations

The Comanche mock-up that we used for this evaluation currently cannot be rolled onto its side or inverted for any emergency egress trials. We do not currently possess the equipment to make this possible without irreparably damaging the mock-up. We had already identified this limitation early in the preparations for the evaluation and planned to acquire the proper equipment to safely roll and invert the mock-up for future studies. TOP 7-3-529 recognizes this limitation as normal and directs evaluators to obtain a subjective evaluation from each participant, based on their experiences during the evaluation. One portion of the post-evaluation questionnaire addresses this limitation.

The STA mock-up lacks nearly every normal subsystem that would typically be installed on a helicopter. In particular, there is no rotor blade system, and the lack of one became especially highlighted during the pilot study conducted in early June 2003. During the pilot study and formal trials, several people conducted emergency egress trials out the right window by actually standing up on the edge of the right window (instead of simply swinging their legs over and sitting) before jumping out and to the safety mats below. As they stood up to almost full height, each became aware that his or her head would have almost certainly come into contact (probably fatally) with the still-spinning rotor system, even if it had little kinetic angular velocity and energy remaining as it wound down (see figure 11). For this evaluation, subjects were briefed about the lack of a rotor system and to be cognizant of where the tip-path plane of the rotor blades would likely be during an emergency egress.

Figure 11. Large percentile male participant conducts an emergency egress from the front crew station through the right window by standing on the edge of the window. (If the participants had stood to full height, the rotor system on a real aircraft would have likely contacted his head. This situation would have been exacerbated by an egress from the rear crew station.)

This evaluation assessed Block 1 of the AW ensemble. For chemical-biological (CB) protection, Block 1 uses the central processing unit worn underneath the ABDU. AW Block 1 will likely be used for further developmental testing, limited user testing, and some operational testing in the Comanche over the next 4 to 5 years. In contrast, AW Blocks 2 and 3 will employ the Joint Protective Aircrew Ensemble (JPACE), a lightweight, CB protective ensemble worn as a substitute for current flight suits in a CB environment. It will be combined with CB head-eye-respiratory equipment to provide an integrated, modular CB protection system for flight and ground operations. The JPACE ensemble will likely be used by the units first equipped with the Comanche around the 2009 time frame.

3.6.2 Air Warrior Limitations

One component of the AW ensemble that was worn during the evaluation was the MCG. However, the Comanche mock-up does not have a working MCU to actually pump the water through the vest and cool the pilot. Thus, the subjects did not experience the cooling effect of the garment.

3.6.3 STA Crew Station Limitations

Another limitation of this evaluation to be discussed concerns the crashworthy seats in the Comanche. As previously discussed, the crew seats were designed with energy absorbers and frangible floor panels so that the seat will "stroke" downward in a high energy crash, providing an additional measure of aircrew survivability. This characteristic is true of most U.S. military helicopters, particularly those with tandem seating configurations. However, it is important to note that the seats will actually stroke *through* the bottom of crew station fuselage. Our mock-up was not able to simulate this seat stroking since it would have irreparably damaged the mock-up. A fully stroked seat will likely present a more difficult egress situation for a wide anthropometric range of pilots. In addition, it is very likely that the instrument panel will dislodge and crash downward into the pilot's lower body, causing an even more difficult egress situation.

During the conduct of the evaluation, several more limitations became apparent. First, the quick-disconnect cable (QDC) did not work on several occasions during the practice period before the formal trials. This presented a significant safety hazard since a participant's head could be jerked violently if the QDC failed while the participant jumped from the aircraft. Manual disconnect of the QDC was not a desirable option since it would not be a required step during emergency egress (i.e., the QDC should perform automatically without pilot intervention). Instead, we decided to route the plug end of the HIDSS QDC into the AW vest near the pilot's torso during the trials, thereby eliminating the safety hazard.

Similar to the HIDSS cable, the participants did not have a location to plug the MCG cable into the MCU. The result was about 1 to 2 inches of cable and connector protruding from the MCG and ABDU. Thus, we were not able to test the pilot's ability to connect the MCG cable during normal ingress, disconnect it during normal egress, or evaluate the QDC during emergency egress.

RAH-66 seats had not yet been manufactured. Therefore, the seats used in the evaluation were UH-60 Blackhawk seats. Likewise, the restraint harness system was slightly different. This caused several instances of pilots having trouble fastening their restraint harness. However, the steps required for emergency egress (i.e., disconnecting the restraint harness) were no different from the production model RAH-66, so we feel this limitation had negligible impact on performance.

The SAC used during the evaluation was a wooden replication with a 3-inch pin running through the center to connect to the SAC box. It broke away twice during the evaluation during egress

trials through the right window. The production model SAC had the following breakaway forces, depending on the axis of force (personal communication, Steven Ratka, 30 October 2003):

- Longitudinal - 1334N (300 lb)
- Lateral - 667N (150 lb)
- Directional (yaw) - 23N-M (200 in.-lb)
- Up-Down – 667N (150 lb)

We do not know how similar or dissimilar the breakaway strengths on our mock-up were compared with the production SAC.

Finally, 32 of the trials involved emergency egress through the left or right window after a simulated ignition of the window jettison system via the D-ring grasp handle between the pilot's legs. Our mock-up used Plexiglas[9] screens to replicate the canopy windows, which we simply removed before emergency egress trials involving exits through the windows. After the pilot jettisons the windows in a real aircraft with the pyrotechnic charge, there will certainly be glass shards around the edges of the windows over which a pilot must crawl to leave the crew station. These shards may slow emergency egress and probably cause minor laceration injuries to the pilot.

3.7 Data Analysis

The data from the evaluation are in two main sections. The first section is the objective data taken by the timing of each of the ingress-egress trials. The second section of data are the subjective ratings and expert observations from the participants.

The times from the normal ingress and egress trials are simply reported with no descriptive statistics calculated. The reason was that subjects were under no time pressure to complete these trials, and they were instructed to complete them at a normal pace. We were more interested in capturing comments on movement difficulties, potential safety problems, volume-of-space issues, and physical layout of the AW equipment against the crew station structure. We also used the motion capture equipment to acquire data about their natural movements and then later incorporated those onto 3-D human figure models.

Descriptive statistics were calculated to determine if the overall average emergency egress time was less than 30 seconds. The data were further separated and analyzed to assess other comparisons between subjects, crew station, AW ensembles, and egress routes. Exploratory data analysis showed that we could not assume a normal distribution in most cases. Therefore, we performed data analysis of the emergency egress times with nonparametric statistics.

[9]Plexiglas is a registered trademark of Roehm.

The second section body of data were the subjective ratings taken via questionnaire at the end of each trial and at the conclusion of the evaluation. The "yes-no" questions were analyzed with binomial tests and bar charts. The comments were analyzed and grouped into themes. For the second questionnaire, the answers to the questions used a Likert-type scale; thus, they required nonparametric tests. As with the emergency egress times, we compared responses for front versus rear crew station, AW configuration, and left versus right egress route. We used the Wilcoxon Signed Ranks Test (WSRT) for these three comparisons. To compare subjective ratings among the four anthropometric sizes of the subjects, the Kruskal-Wallis Test was used, a nonparametric equivalent of the analysis of variance (ANOVA). A *post hoc* analysis was completed with Mann-Whitney U[10]. Because of the small sample size, Fisher's Exact Test was used in all pairwise comparisons. In addition, results of the comparison were graphed on bar charts. The results of the egress times were compared to the subjective ratings to see how the participants' perceptions of the ease or difficulty of egress compared to their times to actually egress.

4. Results

4.1 Normal Ingress and Egress Trials

Times from the 32 normal ingress and egress trials (eight per participant) are shown in table 3. The smaller participants (females) generally completed the trials faster than larger males.

Table 3. Normal ingress and egress times for each participant.

Task	Clothing	Crew Station	Subject 1	Subject 2	Subject 3	Subject 4
			Large Male	**Small Female**	**Medium Male**	**Medium Female**
Ingress	Combat-Hot	Front	03:51.0	02:47.0	03:15.0	02:06.0
Egress	Combat-Hot	Front	00:56.0	00:48.0	01:18.0	00:32.9
Ingress	Combat-Hot	Rear	03:45.0	03:28.1	03:48.0	03:05.0
Egress	Combat-Hot	Rear	01:11.0	00:32.0	01:39.0	00:59.8
Ingress	MOPP IV - OW	Front	05:29.0	05:20.0	11:16.0	05:05.0
Egress	MOPP IV - OW	Front	01:43.0	00:37.0	01:12.0	01:07.0
Ingress	MOPP IV - OW	Rear	08:10.0	06:26.0	07:50.0	09:17.0
Egress	MOPP IV - OW	Rear	02:23.0	00:19.0	01:19.5	00:52.0

4.2 Emergency Egress Trials

Times from the 48 emergency egress trials (12 per participant) are shown in table 4. Overall mean time to conduct emergency egress was 16.6 seconds, well within the 30-second standard in MIL-STD-1472 and JSSG 2010-11. There were two instances when a participant did not meet the 30-second standard; both were from the large male. Average emergency egress times are

[10]The test involves the calculation of a statistic, usually called *U*, whose distribution under the null hypothesis is known.

further categorized by crew station, egress route, and participant in table 5 and shown graphically in figure 12.

Table 4. Emergency egress times.

Clothing	Route	Crew station	Subject 1 Large Male	Subject 2 Small Female	Subject 3 Medium Male	Subject 4 Medium Female
Combat-Hot	Normal	Front	00:39.4	00:09.8	00:11.1	00:06.6
Combat-Hot	Left Window	Front	00:24.6	00:07.8	00:10.3	00:05.6
Combat-Hot	Right Window	Front	00:25.7	00:09.1	00:16.5	00:08.6
Combat-Hot	Normal	Rear	00:21.4	00:12.8	00:15.0	00:27.2
Combat-Hot	Left Window	Rear	00:14.4	00:10.1	00:15.6	00:10.2
Combat-Hot	Right Window	Rear	00:18.9	00:13.9	00:16.7	00:12.5
MOPP - OW	Normal	Front	00:27.0	00:14.4	00:14.4	00:09.8
MOPP - OW	Left Window	Front	00:15.2	00:11.9	00:13.5	00:07.7
MOPP - OW	Right Window	Front	00:15.5	00:14.8	00:25.5	00:16.8
MOPP - OW	Normal	Rear	00:25.0	00:16.8	00:17.1	00:17.0
MOPP - OW	Left Window	Rear	00:17.4	00:19.2	00:28.6	00:09.7
MOPP - OW	Right Window	Rear	00:36.2	00:23.3	00:25.1	00:13.5

Table 5. Emergency egress means.

Average emergency egress time	
	00:16.6
Average emergency egress time per seat	
Back	00:18.2
Front	00:15.1
Average emergency egress time per exit route	
Left door	00:17.8
Left window	00:13.9
Right window	00:18.3
Average emergency egress time per subject	
Small female	00:13.7
Medium female	00:12.1
Medium male	00:17.4
Large male	00:23.4
Average emergency egress time per ensemble	
Combat-hot	00:15.2
MOPP-OW	00:18.1

The difference in emergency egress times between front and back crew stations was statistically significant (WSRT, $T = -2.186$, $p = .029$). Similarly, the difference between the two AW configurations was statistically significant (WSRT, $T = -1.929$, $p = .05$). When we look at the three egress routes, the Kruskal-Wallis Test shows that the differences in mean egress times were not statistically significant (K-W, $H = 1.75$, $p > .05$). However, there was a significant difference in times between subjects (K-W, $H = 17.622$, $p = .001$). A *post hoc* analysis via Mann-Whitney U showed a significant difference between the medium female and medium male (M-W, $U = 29.5$ $p = .014$); the medium female and large male (M-W, $U = 16.0$, $p = .001$); and the small female and medium male ($U = 15.5$, $p = .001$).

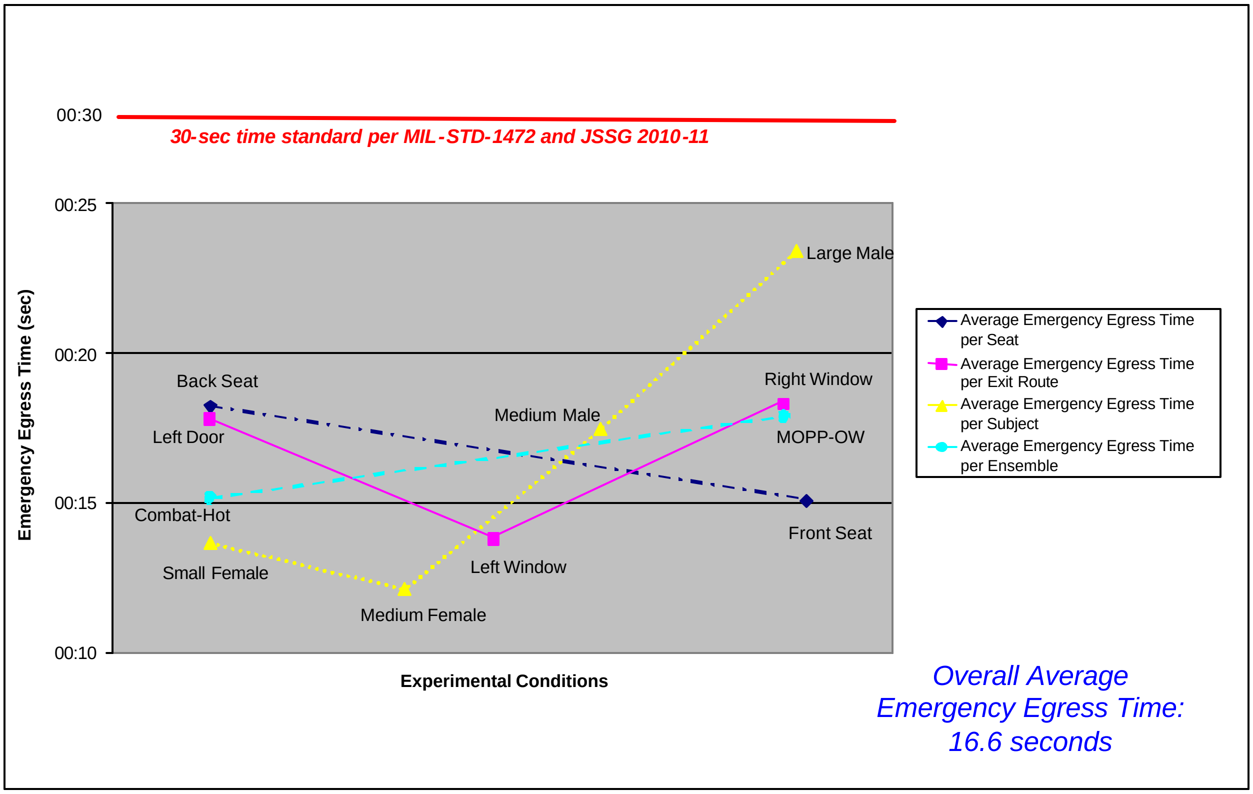


Figure 12. Emergency egress means by experimental condition.

4.2.1 Learning Effects

Times from each emergency egress trial were graphed by participant in the order that the trials were executed without regard for AW configuration (combat-hot [C-H] or MOPP-OW) or crew station position (front or rear). Each participant completed 12 emergency egress trials that, in accordance with table 2, were executed in groups of three: left door, left window, right window. Figure 13 displays the emergency egress times in order of execution.

We performed a split-half analysis on each participant's group of trials, comparing the first half of trials against the second half with a simple t-test. A comparison of all four participants' first six trials (mean time of 18.7 seconds) against the second half of trials (mean time 14.6 seconds) showed that the second half was significantly faster ($t = 3.06$, $p < .005$).

When we compared the first half of trials to the second half for each participant, the average of their second half was always faster than the first. However, only the small female showed a significantly faster egress time ($t = 4.358$, $p < .005$). The other three subjects performed the second half faster, but the difference was not statistically significant. Therefore, we conclude there was a mild training effect.

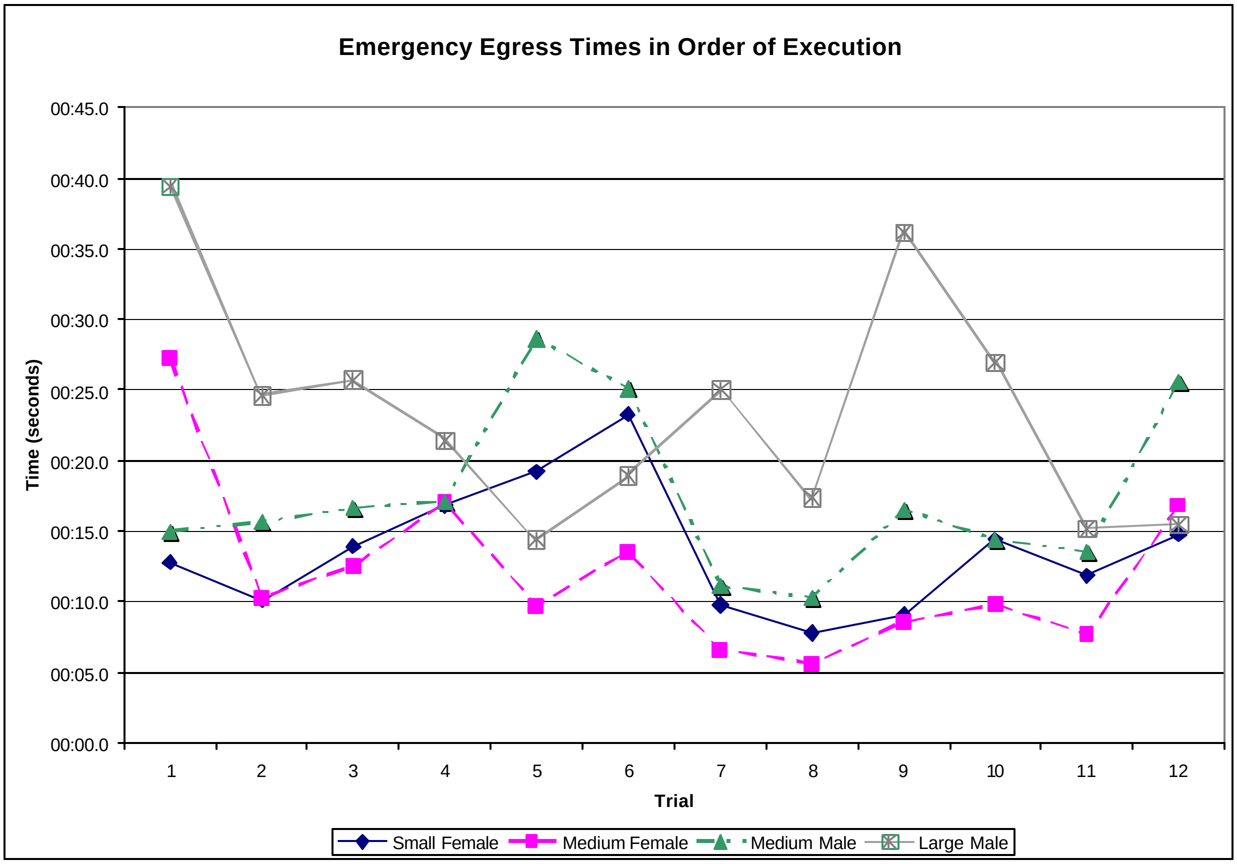


Figure 13. Emergency egress times in order of execution.

4.3 Questionnaire Results

A nonparametric analysis of the questionnaire results generally mirrors the results from the emergency egress times (see table 6 for comparison). See appendix F for a graphical analysis of the questionnaire results and listing of the comments taken on post-event questionnaires. Analysis shows a statistically significant difference in subjective ratings between the two AW configurations (WSRT, $T = -3.922$, $p = .000$), meaning that the subjects felt emergency egress was markedly more difficult in the MOPP-OW configuration than C-H. Likewise, they felt it was more difficult to conduct egress through the right side versus the left side of the aircraft, and the difference was statistically significant (WSRT, $T = -2.739$, $p = .006$). However, the difference in overall ratings between the front and rear crew station were not statistically significant (WSRT, $T = -.577$, $p > .05$).

Table 6. Comparison of objective (egress time) and subjective results (questionnaire).

Independent Variable	Objective Results (egress times)	Subjective Results (questionnaire results)
AW configuration	C-H faster	C-H easier
Front versus rear crew station	Front faster	No statistical difference
Anthropometric size	Smaller participants (females) faster	Egress easier for smaller participants (females) than larger participants (males)
Egress route (left versus right)	Left side faster	Left side easier

When we compared the subjective ratings among the four anthropometric sizes (each pilot), there was a statistically significant difference (K-W, $H = 29.719$, $p = .000$). A *post hoc* analysis by Mann-Whitney U showed significant differences between small female and medium male, small female and large male, medium female and medium male, and medium female and large male.

Pilots reported problems with ingress or egress in 66 of 80 trials (see appendix G for graphical analysis and listing of the comments taken on the post-trial questionnaire). The following major comments were reported:

- Significant foot entrapment or obstruction below the left multipurpose display (LMPD) or right multipurpose panel display (RMPD) (30 of 80 trials);
- Kicked glare shield or displays (30 of 80 trials);
- Three of four pilots (small female, medium male, large male) not able to reach canopy door to close it;
- SAC broken off (twice) and significant contact with SAC (four times) in 16 egress trials through right window;
- Helmet and body contact with canopy and structure (31 of 80 trials);
- Equipment (AW, cords) and seatbelt entanglements (5 of 48 emergency egress trials);
- Participants had difficulties reaching and seeing crew station controls or stepping up and down from aircraft while wearing MOPP-OW configuration (four occurrences).

The following safety and damage problems were observed:

- HIDSS anchor cable snapped apart once and QDC did not work.
- Pilots' AW equipment caught on window sill several times, causing a fall to the ground (subject was supported by spotters).
- In one emergency egress trial, pilot wedged helmet between seat head rest and right armor wing panel upon egress. Pilot had a more "laid back" position to get feet out left window. As helmet wedged tight, pilot pulled forward to conduct egress, pulling head out of helmet. Head not allowed to move farther because he was caught on mask and hood straps and seat belt. Likely the subject would not have been able to free himself and conduct egress from the aircraft during an emergency. Trial halted at 13 seconds and repeated.
- Numerous contacts between helmet and front seat windscreen, helmet tracker, and mirrors while in the front seat.
- Occasional contact between shoulders and back with door left and right windows, causing excessive scratching.
- When the aircraft retained unit (ARU) was stowed on the hooks in the front and back crew stations, the participants frequently struck the ARU with their heads when they entered the

crew stations. Because of the likelihood of the ARU striking the participant's eyes during ingress, the P.I. decided that the ARU would not be stowed on the hooks during ingress. Consequently, the ARU was mounted to the helmet (by the pilots) before they entered the crew stations.

Pilots reported the following major comments and recommendations on post-event questionnaires (see appendix F):

- Provide a method to close canopy doors, which is at the top of the door hinge (so all can reach it; too far to reach currently).

- Recommend some design where SAC has a breakaway or is collapsible during egress to the right side.

- Glare shield over console should have breakaway sections on the sides. Foot could get trapped upon egress.

- AW 9-mm holster in standard position on right thigh does not work in the Comanche, especially in the front seat. Must shift personal weapon to calf of either leg.

- Most tasks with AW and MOPP are blind. Could not see the key border right panels without major shifting on the seat.

- AH-64D has markings to help pilots follow down to steps; that would help on Comanche.

- Do not rest on the edge of the window during (emergency) exit; push away from aircraft with foot so not to get caught on the window pull handle.

4.4 Jack and Motion Capture

Even with the difficulties encountered in collecting motion capture data, a replay of the motion capture from various viewing angles with the Jack software helped us to detect some of the problems encountered by the large male pilot during the early trial exercises. In particular, during egress of the forward crew station, the motion capture clearly shows how the large male pilot had some difficulty clearing the knee and foot past the outboard edge of the glare shield on the left-hand side of the instrument panel (see figure 14). This analysis graphically confirms observations from the participants and authors during multiple trials.

Results show that the combination of human figure models and motion capture data can prove to be a useful tool in analyzing the complex biomechanical motions required for crew station ingress and egress.

Figure 14. Jack and motion capture data show problem with the LMPD and glare shield by the large male pilot.

5. Summary

Following is a summary of the results from the ingress-egress evaluation. The average emergency egress of 16.6 seconds was well under the 30-second time standard. During 80 trials, none of the participants were injured. Of the 48 emergency egress trials, all but two (both performed by the large male) were completed within 30 seconds. A statistical analysis shows that the egress times were significantly faster from the rear crew station than the front and significantly faster in the C-H AW configuration than the MOPP-OW configuration. Emergency egress times were faster out the left side than the right side, but the difference was not statistically significant. Emergency egress times generally increased as anthropometric size increased, with significant differences between medium female-medium male.

Results from the subjective questionnaires generally mirror the objective data (see table 7). Subjective ratings showed that participants felt that egress was more difficult in the MOPP-OW ensemble (statistically significant), and the egress to the right side was more difficult than the left side (statistically significant). Subjective ratings did not reveal a feeling that egress was more difficult from the front seat than the back seat. However, commentary from these participants

(particularly the two males) shows that they feel egress is much more difficult from the front seat because of the lower volume of space as compared to the rear seat. A comparison of subjective ratings between anthropometric sizes (all four subjects) showed a general increase in difficulty as anthropometric size grew, with significant differences occurring between small female and medium male, small female and large male, medium female and medium male, and medium female and large male.

Analysis for a training effect shows that subjects were generally faster in performing their second half of emergency egress trials than their first half. As a group, this difference was statistically significant. As individuals, each person performed faster in the second half, but only the small female showed a statistically significant difference.

Pilots reported problems with ingress or egress in 66 of 80 trials. There was significant foot entrapment or obstruction below LMPD or RMPD plus kicking of the glare shield or displays. The Jack and motion capture data clearly show how the larger pilots had difficulty clearing the knee and foot past the outboard edge of the glare shield on the left-hand side of the instrument panel.

6. Recommendations

To enhance ingress and egress performance in the RAH-66 with the AW ensemble, the following recommendations were made:

1. Examine methods to reduce or eliminate the foot entrapment and kicking problems associated with the glare shields and map cases, as well as the LMPD and RMPD.
2. Ensure that the SAC breaks away or folds down to aid emergency egress through the right window.
3. Conduct a comprehensive evaluation of the HIDSS, ICS, and MCG cables and where the QDC anchors will be routed on the AW vest and crew station. The Jack anthropometric model used by ARL can be employed to assist this evaluation.
4. The location of the stowage hooks for the ARU in both front and rear crew stations led to frequent contact between the participants' heads and the ARU during normal ingress and egress. Examine possibilities to relocate the ARU stowage hooks to alleviate the contact and possible damage to the ARU.
5. Three of the four subjects could not reach the canopy handle to close the canopy door in either crew station when they wore either AW configuration. Recommend a method or device that allows pilots to easily close the canopy door.

6. There were numerous instances of contact between the helmet and canopy screens and helmet tracker. The windscreens were scratched (particularly the front windscreen). This is a good indication that pilots will damage the windscreens more often than predicted; thus, the windscreens will require replacing more often. Likewise, the helmet trackers are likely to have an increased unscheduled maintenance requirement because of inadvertent contact with the helmet.

7. The standard location for the personal sidearm (currently M9 pistol) and survival knife may need to be altered by larger aviators in the Comanche crew station. Our subjects began to move the sidearm to behind the right calf, and the survival knife was generally worn on the left leg.

8. The results of the training effect analysis argue that the only way to leave the RAH-66 Comanche faster when the AW is worn is for participants to regularly *practice and train to leave the crew station while wearing AW.* We recommend that emergency egress be added to the RAH-66 Aircrew Training Manual and that a certain number of emergency egress task iterations be included on each aviator's commander's task list, whether quarterly, semiannually, or annually. The frequency will likely depend on unit training schedule and current maintenance status.

The Comanche STA at APG offers the opportunity for a number of ensuing evaluations over the next several years. First, there is development testing equipment with other organizations at APG, which would allow us to safely turn the Comanche STA on its side or even upside down and conduct further emergency egress tests in various AW configurations.

In addition, there is the need to conduct an emergency extraction evaluation. In this case, a group of emergency or rescue personnel would be required to physically remove an unconscious or severely injured pilot (simulated) from either crew station wearing various AW configurations. Similar tests were performed in a Comanche prototype aircraft by Sikorsky in May 2003 at West Palm Beach (D'Louhy, 2003).

Another piece of emergency egress equipment available in the crew station is the crew member "breakout" knife. If the canopy jettison does not occur when the jettison system is actuated (via D-ring), the breakout knife should be used to score and then fracture the canopy panel and permit egress. Also, there may be instances when it would be unwise to detonate the jettison explosives because of pooled jet fuel or other petroleum products near the aircraft. In this case, the breakout knife should be used. Subsequent egress evaluations can check the position of the knife in both crew stations to see that it can be reached and used by a wide anthropometric range of pilots wearing various AW configurations.

Block II of AW will be ready for testing in fiscal year 2005 or 2006. The present evaluation can be repeated in the next version of AW with a similar purpose: to determine if ingress and egress can be performed safely and within prescribed time standard (30 seconds), to identify and document any problems, and to make design recommendations as appropriate.

Several recommendations can be made to improve the motion capture process for any future Comanche ingress and egress evaluations. This evaluation was the first attempt at capturing motion in and around a structure of this size and volume where a significant portion of the marker data was occluded. One of the possible solutions to improve the percentage of marker data captured would be to mount the cameras on an overhead boom so that the cameras are looking down into the crew stations. Secondly, additional cameras should be used to provide more marker coverage. A third suggestion would be to investigate placement of the small lipstick cameras inside the crew station at a location that would not interfere with the ingress or egress of the subjects and where the cameras would not be kicked or bumped.

The problem of ghost markers could be eliminated by the removal of the windscreens from the canopy frame if possible or if this is not an option, by the covering of the windscreens with a transparent, non-reflective film. Another suggestion might be to substitute a non-reflective black wire mesh that would still allow the markers to be seen from outside the crew stations.

Another problem not previously mentioned could be traced to a split capture volume. The design of this study required the participants to conduct ingress and egress from both sides of the aircraft. This, in turn, required cameras to be set up on both sides of the airframe, which basically split the motion capture volume in two and made calibration of the system difficult. A solution to this problem would be to set up the cameras on just one side of the airframe and then capture all ingress and egress trials on that side, and when those trials are completed, to move the cameras to the opposite side and capture the trials performed from that side of the airframe. This would require additional setup and calibration time but would eliminate the problems stemming from the split capture volume.

7. References

Babbitt, B. A.; Nystrom, C. O. *Questionnaire Construction Manual*; ARI Research Product 89-20; U.S. Army Research Institute for the Behavioral and Social Sciences: Alexandria, Virginia, (ADA212365), 1989a.

Babbitt, B. A.; Nystrom, C. O. *Questionnaire Construction Manual Annex: Literature Survey and Bibliography*; ARI Research Product 89-21; U.S. Army Research Institute for the Behavioral and Social Sciences: Alexandria, Virginia, (ADA213255), 1989b.

Badler, N.; Phillips, C.; Webber, B. (1993). *Simulating humans: Computer graphics, animation, and control.* New York: Oxford University Press.

Barker, C.O.; Bellenkes, A.H. U.S. Naval helicopter mishaps: Cockpit and egress problems. *Aviation, Space, and Environmental Medicine* **1996**, *67*, 480-485.

Bjorn, V. S.; Huang, D. *Physiological and subjective responses to wearing the A/P22-P-9(V) helicopter aircrewman chemical, biological protection ensemble*; Report NAWC/AD-SY-62R-91; Patuxent River Naval Air Station: U.S. Naval Air Warfare Center Aircraft Division, Retrieved 29 June 2003 from http://handle.dtic.mil/100.2/ADB164986, 1992.

Chase, D. J.; Copeland, R. R.; Ferrell, R. J. Comanche crew station development: Mockpit let Comanche fly in simulation long before actual aircraft production. *Program Manager*, *29* (5), 58-60. Retrieved July 6, 2003 from http://www.dau.mil/pubs/pm/pmpdf00/Chass-o.pdf.

Department of the Army. *Ingress, emergency egress, and emergency evacuation testing of Army aircraft: Test operations procedure (TOP) 7-3-529*. ATEC: Aberdeen Proving Ground, MD (ADA246398), 1991.

Department of the Army. *System Training Plan (STRAP) for the Air Warrior.* U.S. Army Aviation Center: Fort Rucker, AL, 2001.

Department of the Army. *System Training Plan (STRAP) for the Joint Protective Aircrew Ensemble (JPACE).* U.S. Army Maneuver Support Center: Fort Leonard Wood, MO, 2002.

Department of the Army. *System Evaluation Report for the Air Warrior Block 1.* U.S. Army Test and Evaluation Command: Alexandria, VA, 2003.

Department of the Army. *Product Manager Air Warrior* [Data file], Retrieved 16 June 2003 from PM Air Warrior Web site, http://peosoldier.army.mil, no date available.

Department of the Army. *Operator's Manual for the RAH-66 Comanche (Draft)*; TM 1-1520-245-10; U.S. Army Aviation and Missile Command: Redstone Arsenal, AL, in press.

Department of Defense. *Military standard: Human engineering design criteria for military systems, equipment, and facilities*; MIL-STD-1472D; Defense Technical Information Center: Virginia, Retrieved July 3, 2003 from http://assist1.daps.dla.mil/eAccess/index.cfm?ident_number=36903, 1989.

Department of Defense. *Design criteria standard: Human engineering*; MIL-STD-1472E; Defense Technical Information Center: Virginia, Retrieved July 3, 2003 from http://assist1.daps.dla.mil/eAccess/index.cfm?ident_number=36903, 1996.

Department of Defense. *Joint service specification guide: Crew systems*; JSSG 2010; Defense Technical Information Center: Virginia. Retrieved July 3, 2003 from http://assist1.daps.dla.mil/eAccess/index.cfm?ident_number=205105, 1998.

D'Louhy, M. (2003). *EMD HDU Emergency Egress Test Report*. Bridgeport, CT: Sikorsky Aircraft Corporation.

Donelson, S. M.; Gordon, C. C. *Anthropometric Survey of U.S. Army Personnel: Pilot Summary Statistics, 1988*; Technical Report Natick/TR-91/040; U.S. Army Natick Research, Development, and Engineering Center: Natick, MA. (ADA241952), Retrieved 30 June 2003 from http://handle.dtic.mil/ 100.2/ADA241952, 1991.

Gordon, C.; Brandtmiller, B.; Churchill, T.; Clauser, C.; McConville, J.; Tebbetts, I.; Walker, R. *Anthropometric survey of U.S. Army personnel: Methods and summary statistics*; Technical Report Natick/TR-89/044; U.S. Army Natick Research, Development, and Engineering Center: Natick, MA, (ADA225094), Retrieved 11 February 2004 from http://handle.dtic.mil/100.2/ADA225094, 1989.

Harrah, D. M.; Kozycki, R.; Salvi, L.; Tauson, R.; Kehring, K. Modeling the air warrior ensemble. *Proceedings of the American Helicopter Society*, *57*, Vol II, 1755-1764, 2001.

Kozycki, R. Developing a modeling and simulation paradigm for assessing the encumbrance of helicopter aircrew clothing and equipment. *Proceedings of the Annual Symposium of the SAFE Association, 36*, 271-279, 1998.

Kozycki, R. Applying human figure modeling tools to the RAH-66 Comanche crew station design. *Proceedings of the SAE Digital Human Modeling Conference*, 2002.

O'Brien, T. G.; Charleton, S. G. *Handbook of Human Factors Testing and Evaluation*. Mahwah, NJ: Lawrence Erlbaum Associates, 81-100, 1996.

Pensotti, L.; Berube, J.; Bucher, B.; Dart, B.; Dunfey, P.; Turieo, M. Designing the air warrior system for optimized human performance. *Proceedings of the Annual Symposium of the SAFE Association, 37*, 49-54, 1999.

Pensotti, L.; Turieo, M.; Stokes, J.; Reeps, S. Feasibility study for a helicopter survival seat pack. *Proceedings of the Annual Symposium of the SAFE Association, 36*, 371-386, 1998.

Rash, C. E. *Helmet-Mounted Displays: Design Issues for Rotary Wing Aviators.* U.S. Army Aeromedical Research Laboratory: Fort Rucker, AL, 1998.

Rash, C. E.; McLean, W. E.; Mozo, B. T.; Licina, J. R.; McEntire, B. J. *Human Factors and Performance Concerns for the Design of Helmet-Mounted Displays*; USSARL Report No. 99-08; US Army Aeromedical Research Laboratory: Fort Rucker, AL, Retrieved 14 June 2003 from http://www.usaarl.army.mil/ TechReports/99-8.PDF, 1999.

Schane, W. P. *Parachute Escape from Helicopters*; USAARL Report No. 74-4; U.S. Army Aeromedical Research Laboratory: Fort Rucker, AL, Retrieved 30 June 2003 from http://www.usaarl.army.mil/TechReports/74-4.PDF, 1974.

Schmidt, J.K.; Winsko, S.J. SH-60B human factors systems safety analysis. *Proceedings of the Eighth International Symposium on Aviation Psychology*,1995; Vol. II, pp 1168-1171.

Swingle, T. R. *U.S. Army rotary-wing emergency egress study*; USAARL Report No. 95-23; U.S. Army Aeromedical Research Laboratory: Fort Rucker, AL, Retrieved 2 July 2003 from http://www.usaarl.army.mil/TechReports/95-23.PDF, 1995.

INTENTIONALLY LEFT BLANK

Appendix A. Target Subject Anthropometry

Measurement	Female		Male	
	5%	50%	50%	95%
Weight	52.64 kg (115.81 lb)	64.74 kg (142.43 lb)	79.29 kg (174.44 lb)	97.17 kg (213.77 lb)
Height	161.17 cm (63.45 in)	167.10 cm (66.00 in)	177.11 cm (69.73 in)	187.75 cm (73.92 in)
Span	164.55 cm (64.66 in)	169.80 cm (66.85 in)	182.71 cm (71.93 in)	195.61 cm (77.01 in)
Buttock-Knee Length	56.80 cm (22.36 in)	59.91 cm (23.59 in)	61.69 cm (24.29 in)	66.52 cm (26.19 in)
Sitting Height	83.58 cm (32.90 in)	88.32 cm (34.77 in)	93.09 cm (36.65 in)	98.18 cm (38.66 in)
Acromion Height, Sitting	53.97 cm (21.25 in)	57.81 cm (22.76 in)	61.31 cm (24.14 in)	65.65 cm (25.85 in)
Biacromial Breadth	34.42 cm (13.55 in)	36.99 cm (14.56 in)	40.11 cm (15.79 in)	42.85 cm (16.87 in)
Bideltoid Breadth	40.38 cm (15.90 in)	43.83 cm (17.26 in)	49.49 cm (19.48 in)	53.87 cm (21.05 in)
Crotch Height	75.54 cm (29.74 in)	78.60 cm (30.94 in)	83.97 cm (33.06 in)	91.51 cm (36.03 in)
Popliteal Height	37.60 cm (14.80 in)	39.97 cm (15.73 in)	43.03 cm (16.94 in)	47.33 cm (18.63 in)
Functional Grip Reach, Extended	72.27 cm (28.45 in)	76.10 cm (29.96 in)	80.55 cm (31.71 in)	86.93 cm (34.22 in)
Chest Depth	20.67 cm (8.14 in)	24.17 cm (9.52 in)	25.01 cm (9.85 in)	28.25 cm (11.12 in)
Hip Breadth	31.97 cm (12.59 in)	35.60 cm (14.02 in)	34.79 cm (13.70 in)	38.09 cm (15.00 in)
Shoulder Circumference	96.13 cm (37.85 in)	103.80 cm (40.86 in)	117.24 cm (46.16 in)	126.75 cm (49.90 in)

INTENTIONALLY LEFT BLANK

Appendix B. Volunteer Affidavit Agreement

VOLUNTEER AGREEMENT AFFIDAVIT:

ARL-HRED Local Adaptation of DA Form 5303-R. For use of this form, see AR 70-25 or AR 40-38

The proponent for this research is: *U.S. Army Research Laboratory*
Human Research and Engineering Directorate
Aberdeen Proving Ground, MD 21005

Authority:	Privacy Act of 1974, 10 USC 3013, 44 USC 3101, and 10 USC 1071-1087
Principal purpose:	To document voluntary participation in the Research program. Social Security number (SSN) and home address will be used for identification and locating purposes.
Routine Uses:	The SSN and home address will be used for identification and locating purposes. Information derived from the study will be used to document the study; implementation of medical programs; adjudication of claims; and for the mandatory reporting of medical conditions as required by law. Information may be furnished to Federal, State, and local agencies.
Disclosure:	The furnishing of your SSN and home address is mandatory and necessary to provide identification and to contact you if future information indicates that your health may be adversely affected. Failure to provide the information may preclude your voluntary participation in this data collection.

Part A • Volunteer agreement affidavit for subjects in approved Department of Army research projects
Note: Volunteers are authorized all necessary medical care for injury or disease that is the proximate result of their participation in such studies under the provisions of AR 40-38 and AR 70-25.

Title of Research Project:	RAH-66 Comanche Ingress-Egress Evaluation	
Human Use Protocol Log Number:	ARL-20098-02005	
Principal Investigator(s):	David B. Durbin	Phone: (334) 255-2069
Associate Investigator(s)	Richard Kozycki Jim Faughn	Phone: (410) 278-5880 Phone: (410) 278-2573
Location of Research:	Building 463, Aberdeen Proving Ground, MD	
Dates of Participation:	February 2002 to July 2003	

I do hereby volunteer to participate in the research project described in the table above. I have full capacity to consent and have attained my 18th birthday. The implications of my voluntary participation, duration, and purpose of the research study, the methods and means by which it is to be conducted, and the inconveniences and hazards that may reasonably be expected have been explained to me. I have been given an opportunity to ask questions concerning this research project. Any such questions were answered to my full and complete satisfaction. Should any further questions arise concerning my rights or study related injury, I may contact the ***ARL-HRED Human Use Committee Chairperson at Aberdeen Proving Ground, Maryland, USA by telephone at 410-278-0612 or DSN 298-0612.*** *I understand that any published data will not reveal my identity. If I choose not to participate, or later wish to withdraw from any portion of it, I may do so without penalty. I understand that military personnel are not subject to punishment under the Uniform Code of Military Justice for choosing not to take part as human subjects and that no administrative sanctions can be given me for choosing not to participate. I may at any time during the course of the project revoke my consent and withdraw without penalty or loss of benefits. However, I may be required (military volunteer) or requested (civilian volunteer) to undergo certain examinations if, in the opinion of an attending physician, such examinations are necessary for my health and well being.*

Part B • To be completed by the Principal Investigator
Note: Instruction for elements of the informed consent provided as detailed explanation in accordance with Appendix C, AR 40-38 or AR 70-25.

Purpose of the Research

This evaluation is investigating the degree to which a Comanche crew station mock-up supports safe and efficient personnel ingress and egress, to include performance under normal and emergency conditions and using appropriate clothing and equipment. The evaluation will be conducted in accordance with the Comanche Ingress-Egress Evaluation Plan. Your participation in the evaluation is expected to last between one and two days. You will be asked to ingress and egress the Comanche mockup approximately 30 to 40 times, including practice and official trials. During approximately 10 of these trials, you will be asked to wear the Nuclear, Biological, and Chemical Protection Mission-Oriented Protective Posture (MOPP) IV ensemble. During 10 of these trials, you will be asked to wear the Air Warrior ensemble with the Over-water vest and raft. During the remainder of trials, you will be asked to wear the standard Air Warrior ensemble. Your performance on official trials will be timed. During and after the evaluation, you will be asked to provide both verbal and written feedback on your experiences and opinions.

Benefits

You will receive no benefits from participating in the study, other than the personal satisfaction of supporting the design of the Comanche helicopter.

Risks

This project presents minimal risk to your health and well-being. As performance of trials will be timed, you may become physically fatigued during the trials. You may also experience some discomfort due to heat, especially when wearing the MOPP IV equipment. Regular rest periods will be provided, and you may stop and rest at any point you choose. There is also the potential for falls, slips, and other mishaps as you ingress and egress the Comanche mockup. Mats will be placed around the mock-up and you will be instructed to perform trials at a safe speed. Spotters will be used to help keep you from falling off the mock-up.

Confidentiality

All data and information obtained about you will be considered privileged and held in confidence. Photographic or video images of you taken during this data collection will not be identified with any of your personal information (name, rank, or status). Complete confidentiality cannot be promised, particularly if you are a military service member, because information bearing on your health may be required to be reported to appropriate medical or command authorities. In addition, applicable regulations note the possibility that the U.S. Army Medical Research and Materiel Command (MRMC-RCQ) officials may inspect the records.

Disposition of Volunteer Agreement Affidavit

The Principal Investigator will retain the original signed Volunteer Agreement Affidavit and forward a photocopy of it to the Chair of the Human Use Committee after the data collection. The project administrator will provide a copy to you.

Contacts for Additional Assistance

If you have questions concerning your rights on research-related injury, or if you have any complaints about your treatment while participating in this research, you can contact

Chair, Human Use Committee U.S. Army Research Laboratory Human Research and Engineering Directorate Aberdeen Proving Ground, MD 21005 (410) 278-0612 or (DSN) 298-0612	**OR**	Office of the Chief Counsel U.S. Army Research Laboratory 2800 Powder Mill Road Adelphi, MD 20783-1197 (301) 394-1070 or (DSN) 290-1070

Obtaining of ASVAB Records

If you are enlisted military, we would like to obtain your Armed Services Vocational Aptitude Battery (ASVAB) scores for use in possible future data analyses. The ASVAB scores will be used strictly for research purposes. The results of any such analyses will be presented for the group of participants as a whole, and no names will be used. With your permission, we will obtain these scores by sending a copy of this signed consent form along with your Social Security Number to the Defense Manpower Data Center (DMDC) in Arlington, VA where ASVAB scores may be obtained from their databases in Arlington, VA or Seaside. CA. If you do not wish your ASVAB scores to be released to the principal investigator, you will still be allowed to participate in the research.

If you would like to participate in this research, please sign one of the following statements, and then complete the information requested at the end of this form:

I AUTHORIZE you to obtain my ASVAB scores. ___________________________
(Your Signature)

I **DO NOT** AUTHORIZE you to obtain my ASVAB scores. _______________________
(Your Signature)

Your signature below indicates that you: (1) are at least 18 years of age, (2) have read the information on this form, (3) have been given the opportunity to ask questions and they have been answered to your satisfaction, and (4) have decided to participate based on the information provided on this form.

***Printed Name of Volunteer** (First, MI., Last)*

Social Security Number (SSN)	***Permanent Address of Volunteer***
Date of Birth *(Month, Day, Year)*	
Today's Date *(Month, Day, Year)*	***Signature of Volunteer***

Signature of Administrator

Appendix C. Subject Actual Anthropometric Results

	Small Female		MediumFemale		Medium Male		Large Male	
Measurement	Raw	Percen -tile	Raw	Percen -tile	Raw	Percen -tile	Raw	Percen -tile
Chest Depth (cm)	22.4	22	20.9	7	30.4	99	29.9	99+
Waist Depth (cm)	18.6	24	18.8	27	27.1	94	27.0	93
Buttock Depth (cm)	23.1	61	24.6	80	28.1	96	31.6	99+
Biacromial Breadth (cm)	29	<1	28.5	<1	45.7	99+	41.5	80
Chest Breadth (cm)	27.6	28	27.2	22	35.7	87	37.9	98
Waist Breadth (cm)	24.5	1	28.2	28	36.8	96	37.7	98
Hip Breadth (cm)	30.8	1	34.1	25	38.0	94	36.4	79
Stature (cm)	152.2	<1	163.4	14	166.7	6	179.8	66
Cervical Height (cm)	125.8	<1	139.0	5	144.7	8	154.1	56
Tenth Rib Height (cm)	95.8	<1	103.6	13	110.5	37	115.7	77
Iliocristale Height (cm)	87.2	<1	96.8	3	98.6	3	113.7	88
Bideltoid Breadth (cm)	41.1	10	41.0	9	51.8	83	53.1	93
Waist Front Length (Omphalion) (cm)	31.9	<1	35.4	<1	33.2	<1	41.5	42
Waist Height (cm)	90.5	<1	96.5	3	101.6	16	108.0	63
Gluteal Furrow Height (cm)	65.2	<1	73.1	10	76.6	13	86.0	86
Thigh Circumference (cm)	56.2	30	58.5	50	62.7	78	65.5	92
Calf Circumference (cm)	35.7	47	39.1	92	41.3	93	40.0	83
Lateral Femoral Epicondyle (cm)	42.2	<1	44.8	5	48.5	22	54.1	93
Trochanteric Height (cm)	78.7	<1	84.1	5	92.5	55	96.2	81
Knee Height, Midpatella (cm)	40.2	<1	44.9	7	48.3	22	55.3	97
Knee Circumference (cm)	34.5	14	38.0	67	39.2	61	41.5	90
Foot Length (cm)	22.7	<1	23.3	5	24.7	3	29.2	97
Ball of Foot Length (cm)	16	<1	17.3	10	16.7	<1	21.0	90
Foot Breadth (cm)	9.5	85	9.0	50	10.0	50	10.8	95
Lateral Malleolus Height (cm)	4.5	<1	6.3	45	6.2	8	5.9	2
Knee Width Sitting (cm)	9.3	N/A	11.4	N/A	10.5	N/A	12.1	N/A
Popliteal Height (cm)	35.8	<1	38.1	10	40.2	9	46.0	87
Crotch Height (cm)	68.2	<1	73.1	<1	76.2	2	88.4	83
Biceps Circumference, Flexed (cm)	28.5	57	28.1	50	36.0	86	30.6	10
Forearm Circumference, Flexed (cm)	24.4	24	24.2	20	30.0	52	30.3	60
Acromion-Radiale Length (cm)	28.7	<1	29.6	<1	34.2	47	33.6	34
Radiale-Stylion Length (cm)	21.5	<1	24.1	27	25.2	11	27.0	55
Hand Length (cm)	16.5	<1	16.8	1	18.6	15	23.3	99+
Palm Length - St to Web (cm)	9.3	N/A	9.6	N/A	11.1	N/A	13.1	N/A
Palm Length - St to Knuckle (cm)	7.3	N/A	7.7	N/A	8.1	N/A	9.8	N/A
Hand Breadth (cm)	7.2	<1	7.4	2	9.3	76	10.3	99+
Hand Circumference (cm)	18.7	45	19.1	65	20.7	21	24.5	99+
Wrist-Center of Grip Length (cm)	5.2	<1	5.7	1	7.4	90	8.7	99+
Head Length (cm)	18.5	30	19.0	60	19.1	10	21.0	96
Head Breadth (cm)	14.2	25	14.6	60	15.1	35	15.5	65
Menton-Top of Head (cm)	20.5	5	19.6	<1	21.2	1	24.3	94
Tragion-Top of Head (cm)	12.2	30	12.5	55	12.4	12	13.9	94
Neck Circumference (cm)	32.3	67	33.1	82	40.2	87	44.0	99+
Sitting Height (cm)	81.0	<1	89.1	61	85.6	2	89.9	18
Cervicale Height, Sitting (cm)	56.4	<1	65.0	43	63.9	4	64.7	7
Thigh Clearance (cm)	13.7	2	15.1	25	16.7	47	18.0	96

Buttock-Knee Length (cm)	54.0	<1	57.1	8	60.7	35	62.6	63
Eye Height, Sitting (cm)	69.8	<1	77.6	60	73.5	2	76.7	9
Acromial Height, Sitting (cm)	52.5	2	61.5	93	58.3	15	59.8	30
Hip Breadth, Sitting (cm)	39.9	54	42.4	82	43.9	99+	42.6	99+
Functional Grip Reach (cm)	61.0	<1	68.0	20	71.8	18	76.4	64
Functional Grip Reach, Extended (cm)	75.9	46	78.0	77	85.2	89	86.4	93
Stylion-Stylion Span (cm)	117.3	N/A	127.8	N/A	137.4	N/A	----	----
Weight (lb)	118	7	130	23	180	60	204	89

Appendix D. Questionnaire

Soldier Demographic/Anthropometric Data

1. Personal Identification Number (PIN): ____ ____ ____ ____ ____ (Last name initial + Last Four)

2. Date of Birth: ____________ (DD/MMM/YY) 3. Rank:____________ 4. Date of Rank:____________ (DD/MMM/YY)

5. Basic Service Entry Date: ______________ (DD/MMM/YY)

6. Current Unit: 7. Current Job Title:

8. Primary Military Occupational Specialty (PMOS):

9. How long in this PMOS? _________________________

10. What is your primary aircraft? 11. Secondary aircraft?

12. Total Flight Hours: _______________

13. Flight activity category (FAC): 1 2 3 14. Readiness Level (RL): 1 2 3

15. Sight Correction while flying (check if yes): ☐

16. Correction type: Glasses ☐ Contacts ☐ NA ☐

17. PULHES: _______________

18. Are you on a temporary or permanent P2/P3 profile? _____________________________

19. Place a check mark by the aircraft you are qualified to fly and annotate approximate flight hours for each aircraft.

Aircraft	**Qualified**		**Total Hours**
	Yes	**No**	
AH-64A (Apache)			
AH-64D (Apache Longbow)			
AH-1(Cobra)			
AH-6/OH-6 (Cayuse)			
OH-58A/C (Kiowa)			
OH-58D (Kiowa Warrior)			
UH-1 (Iroquis)			
UH-60 (Blackhawk)			
CH-47 (Chinook)			
Other:			

Ingress-Egress Trial Questionnaire (Observer)

Pin # ________________ Date: _______________

Trial #: ____________________ Temperature: ________F

Time it took to ingress / egress (circle one) ____________ seconds

1. Any ingress-egress problems observed or reported during trial? Yes ____ No ____
2. Any safety problems observed or reported during trial? Yes _____ No _____
3. Any damage to the mock-up? Yes _____ No _____

Description of any 1) ingress-egress problems, 2) safety problems, 3) damage to mock-up

Ingress-Egress End-of-Phase Questionnaire (Participant)

Pin # _______________ Date: _______________

Clothing ensemble worn during the trials you just completed: (Circle one)

MOPP IV & Overwater / Combat Standard Gear

1. Rate how easy or difficult it was to ingress and egress the front and rear crew stations with the clothing ensemble you wore during the last set of trials.

Task	Very Easy	Somewhat Easy	Borderline	Somewhat Difficult	Very Difficult
Ingress front crew station via canopy door (normal)					
Egress front crew station via canopy door (normal)					
Ingress rear crew station via canopy door (normal)					
Egress rear crew station via canopy door (normal)					
Egress front crew station via left window					
Egress front crew station via right window					
Egress rear crew station via left window					
Egress rear crew station via right window					

2. Are there any improvements that could be made to the crew stations that would enhance ingress and egress?

Yes _____ No _____

If yes, describe the improvements that could be made to the crew station(s):

3. Do you have any suggestions for improving the method of ingress and egress that you used during this phase?

Yes _____ No _____

If yes, describe the improvements that could be made to the method that you used:

* One limitation of this study was that the mockup could not be laid on its side or be inverted. Given your experiences during the conduct of this study, please judge your ability to reach and open the exits and make an emergency egress under those possible conditions

1	2	3	4	5
Very Easy	Somewhat Easy	Borderline	Somewhat Difficult	Very Difficult

Appendix E. Checklists

GENERAL CHECKLIST PRIOR TO EACH TRIAL

- Ensure seating position already dialed in for subject (will require pre-check and marking for each subject)
- AW personnel check AW fitting on subject
- For MOPP IV-OW condition, take out seat back cushion to allow for life raft.
- Instruct subject to stop the trial if they are endangering themselves or if they damage the mock-up.
- Ensure safety devices (mats and tyvek foam bed) are in position
- Remove windows (both sides) for emergency egress trials
- Water / Gatorade on hand
- Box fans on hand and running
- Ensure motion capture cameras in correct locations (front/rear seat)
- Set up placards for HIDSS motion capture trials

INGRESS CHECKLIST

- Subject stands at 5 foot line from crew station (depending on seat being tested), with kneeboard and helmet in hand. Crew station seat will be adjusted for each subject prior to each trial.
- PI ensures safety personnel are in position.
- Videographer posts new trial data on mockup.
- PI cues video recording to begin, then announces description of trial (trial #, date, ingress, front/rear seat, subject # by PIN, AW ensemble condition).
- PI announces 'Go', PI and AI begin digital stopwatches.
- Subject approaches crew station, simulates using lever to open door, lifts up door, and begins ingress to the seat. The following steps should occur, but the order in which they occur is at the discretion of the subject:
    - Fasten restraint harness
    - Don helmet
    - Don ARU
    - Connect HIDSS cable
    - Simulate connecting MCU cable
    - Deploy CIK
    - Deploy armor wing panels
    - Strap on kneeboard
    - Reaches up to close and latch door (simulate latching)
    - Velcro the handholds into stowed position
    - Place hands and feet on flight controls
- Signals PI to stop trial either verbally or by thumbs-up hand signal.
- PI announces elapsed time of trial for the video recording system, but video capture continues.
- PI asks participants a series of questions from the end-of-trial questionnaire, including asking the subject to demonstrate that they can reach and view the crew station controls and displays, and have adequate visibility over-the-nose of the mock-up.
- AI records responses from subject on questionnaire form.
- PI announces end of trial and directs video capture to pause.
- Note[1]: For MOPP/OW trials, remove the seatback cushion from the front and rear crew station seats prior to ingress.
- Note[2]: Pilots need to perform scan pattern for HIDSS/head movement analysis.

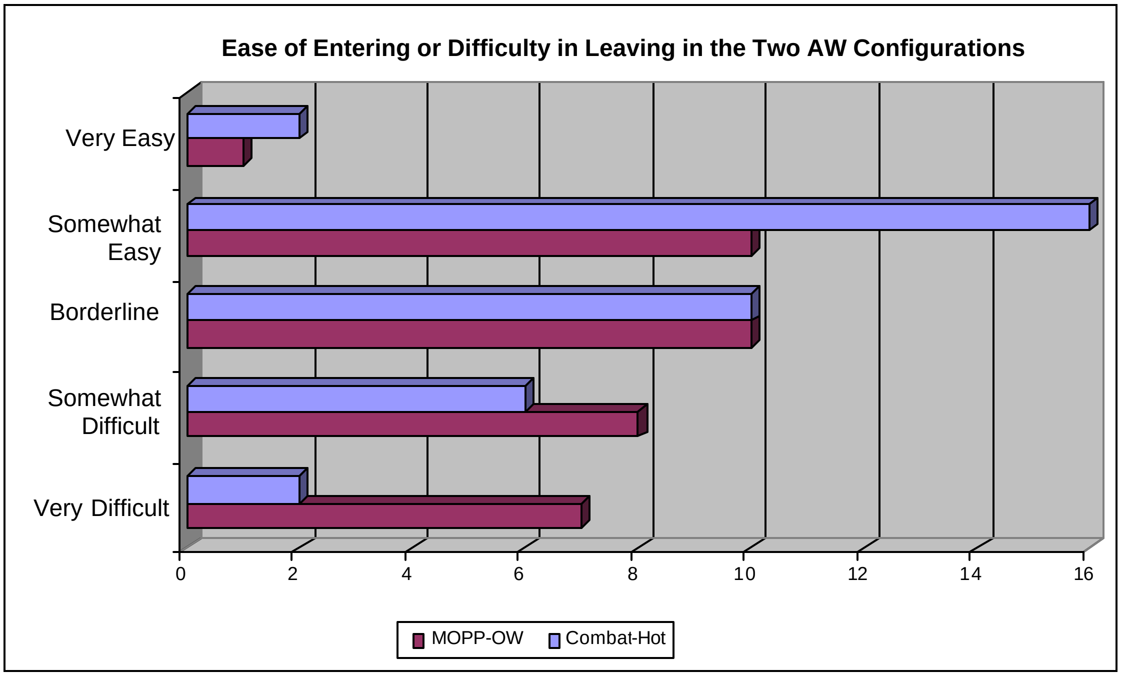
NORMAL EGRESS CHECKLIST

- Participant seated in mockup in the same condition as the end of an ingress trial.
- PI ensures safety personnel and equipment are in position.
- PI cues video and motion capture recording to begin, then announces description of trial (trial #, date, normal egress, front/rear seat, subject #, AW ensemble condition)
- PI announces ‘Go’, PI and AI begin digital stopwatches.
- Subject egresses normally from the crew station per the following steps (in the order they deem most appropriate):
    - Release restraint harness
    - Stow CIK
    - Retract armor wing panels
    - Manually detach HIDSS and MCU cables (simulated)
    - Doff helmet
    - Doff ARU
    - Release door latch (simulated) and push on door to raise it
    - Unstrap kneeboard (optional)
    - Unvelcro handholds
- Subject raises torso and legs, then egresses the aircraft.
- PI/AI stops time when subject has both feet on the ground or safety mats; AI announces elapsed time, motion capture and video capture stops.
- AI asks subjects a series from the end-of-trial questionnaire, AI records responses from subject on the questionnaire form.
- PI announces end of trial.
- Note: For MOPP trials, pilots need to don the M-45 mask in the crew station.

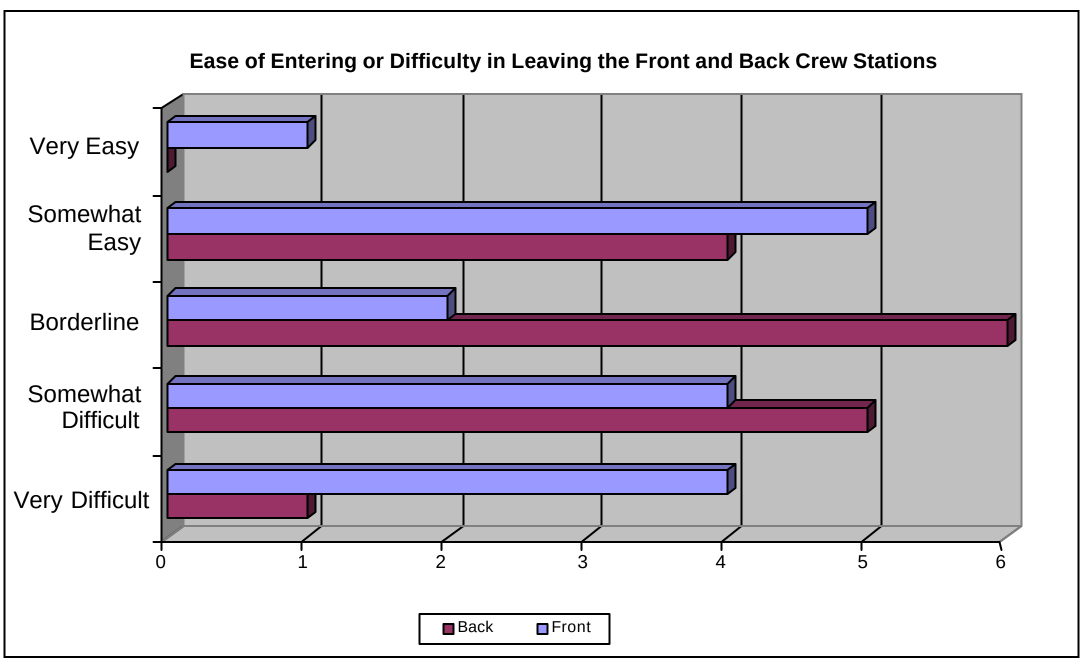
EMERGENCY EGRESS CHECKLIST

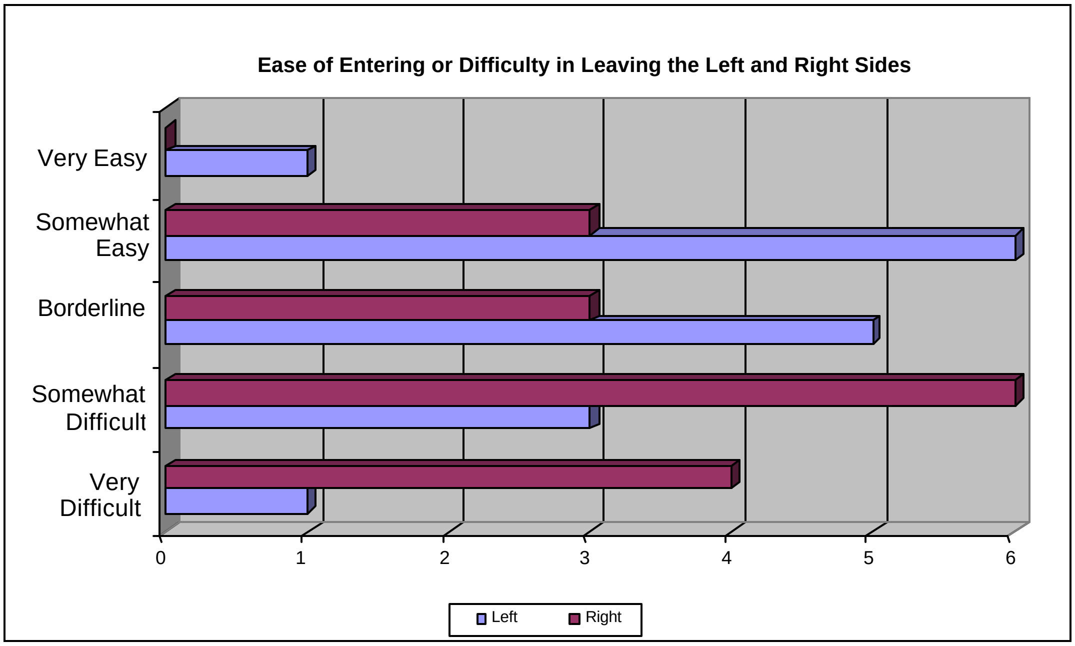
- Participant seated in mockup in the same condition as the end of an ingress trial.
- PI ensures safety personnel and equipment are in position.
- Remove windows from mockup.
- PI cues video recording to begin, then announces description of trial (trial #, date, emergency egress, front/rear seat, egress direction, subject #, AW ensemble condition).
- PI announces 'Go' and PI/AI begin digital stopwatches.
- Subject egresses the crew station in the fastest manner possible while ensuring safety. The following steps must occur, but the exact order remains at the discretion of the subject (Comanche -10):
    - Helmet visor-down
    - Release restraint harness
    - Retract armor wing panels
    - Stow CIK (optional)
    - Turn ECLs 'off' (simulated)
    - Turn SPU 'off' (simulated)'
    - Turn Battery 'off' (simulated)
    - Pull emergency egress D-ring between legs that blows the windows (simulated) (-or-) Release door latch (simulated) and push on door to raise it (depends on egress path).
    - Unvelcro handholds
    - DO NOT manually detach HIDSS or MCU cables
    - DO NOT doff helmet
- Egresses through the directed window (left or right) or canopy door; step will not be available on the left side.
- AI announces elapsed time in 5 second increments; stops time when subject has reached the ground or safety mats; announces final time for the video capture; motion capture stops.
- AI asks subjects a series of questions from the end-of-trial questionnaire; AI records responses from subject on the questionnaire form.
- PI announces end of trial.

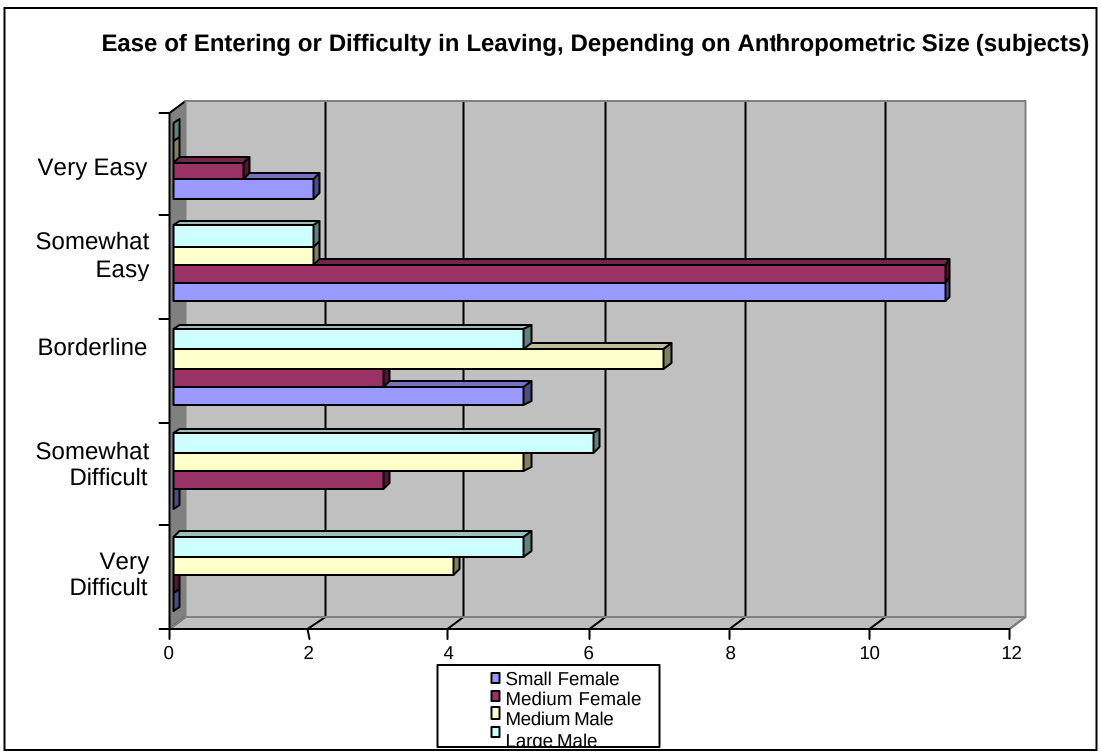
Appendix F. Summary of Pilot Ratings and Comments on Post-Evaluation Questionnaires



1. Rate how easy or difficult it was to conduct ingress and egress from the front and rear crew stations with the clothing ensemble you wore during the last set of trials (either C-H or MOPP-OW).







NOTE: Comments are coded by subject since the comments were largely driven by anthropometric size. SF = Small Female, MF = Medium Female, MM = Medium Male, and LM = Large Male

2. Are there any improvements that could be made in the crew station, which would enhance ingress and egress?

- (SF) Door open/close mechanism that all can reach (i.e., at top of door hinge) like the AH-64

- (SF) No door "tab" to get gear caught on
- (SF) Provide a method to open/close canopy doors that is at the top of the door hinge (so all can reach it – too far of a reach currently)
- (MF) Have no obstacles when egressing [to] the right [side]. Move the SAC further forward or lower it.
- (MF) Removing the door handle or locating it on the side of the window
- (MM) During front crew station right egress, SAC was broken [off]. Recommend some design where it has a breakaway or is collapsible during egress to the right side
- (MM) Glare shield over console should have breakaway sections on the sides. Foot could get trapped on egress.
- (MM) Same comments as for C-H ensemble. Most tasks with Air Warrior and MOPP are blind. Couldn't see the key border right panels without major shifting on the seat. Longbow Apache has markings to help pilots follow down to steps—that would help on Comanche.
- (LM) Front seat would require a redesign to accommodate larger pilots and equipment. CIK limits leg space and movement.
- (LM) SAC interferes with exiting through right window.
- (LM) To put on helmet, canopy windshield is in constant contact; screens will be damaged.
- (LM) Crew station design appears to be fine for pilots that are not in combat or without combat equipment. Air Warrior 9m holster and Comanche do not work together in the front seat.
- (LM) More equipment is less crew station space. With the M45 mask, flight would be impossible. Mask filter restricts head movement. Combat flying in front seat requires more crew station space.

3. Do you have any suggestions for improving the method of ingress and egress, which you used during this phase?

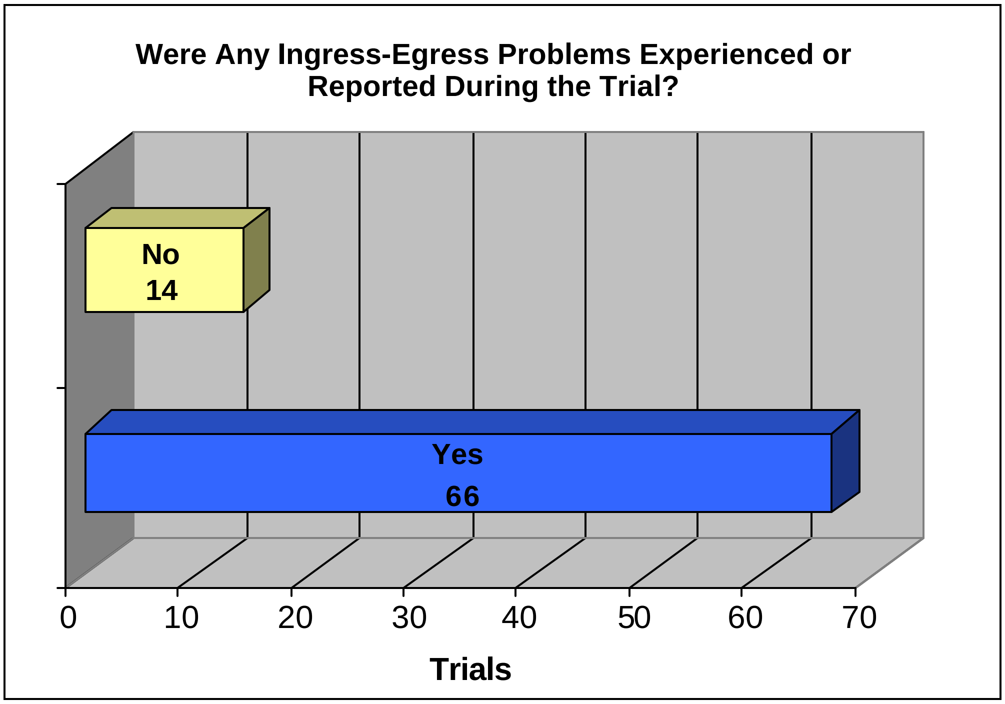
- (SF) Provide a method to open/close canopy doors that is at the top of the door hinge (so all can reach it – too far of a reach currently)
- (MF) Do not rest on the edge of the window when [emergency] exiting, push away from aircraft with foot so not to get caught on the window pull handle.
- (MM) Under current door design, close door before putting on seatbelt. During emergency egress, most trials I had to go out feet first.
- (MM) Front crew station right side egress, couldn't go out feet first.
- (LM) Only the above suggestion [redesign the front crew station to accommodate larger pilots and equipment]. With this amount of equipment Comanche ingress/egress is extremely limited.
- (LM) Engineer front seat for combat equipment. Possibly design overwater raft as permanent part of seat and aircraft as airlines do.

4. One limitation of this study was that the mock-up could not be laid on its side or be inverted. Given your experiences during the conduct of this study, please judge your ability to reach and open the exits and make an emergency egress during those possible conditions.

- (SF) Borderline due to far reach to open/close door

- (MM) Couldn't reach the door handles when seated with the seat belts on. Recommend some type of release handle at the top of the window to release the door from the open position.
- (MM) Front crew station is too cramped. Helmet often contacts front window when putting on the helmet.
- (MM) Couldn't reach door handle from seat in either crew station.
- (MM) Comanche front crew station is not big enough for this [MOPP-OW] configuration. I was constantly shifting my body and moving items to do tasks (put on helmet, mask).
- (LM) Pulling the extra 80 lb up [MOPP-OW] and over would be more difficult.

Appendix G. Summary of Pilot Ratings and Comments on Post-Trial Questionnaires



Foot Entrapment/Obstruction

- During normal ingress, pilot's foot entrapped or obstructed by lower left glare shield/map case (below LMPD) - 4 instances in 16 trials
- During normal egress, pilot's foot entrapped or obstructed by lower left glare shield/map case (below LMPD) – 6 occurrences in 16 trials
- During emergency egress, pilot's foot entrapped or obstructed by lower left or right glare shield/map case (below LMPD or RMPD) – 20 occurrences out of 48 trials
- Foot actually raised collective about 2 in.; then his foot got caught behind collective and seat for a moment
- Significant foot rub upon ingress over window sill, then ECL and SPU/Batt panel

Kicking Glare Shield or Displays During Egress

- During normal egress, kicked left glare shield/map case – 2 occurrences in 16 trials
- During emergency egress, kicked left or right glare shield/map case – 28 occurrences in 48 trials
- Subject forgot to fold CIK back since he couldn't see it; just climbed over it. Major foot contact with CIK, LMPD, and glare shield
- Major foot and leg contact (including knife and pistol) on LMPD, glare shield, left map case, and collective. Had to sit on collective head to complete egress.
- Left foot contact between RMPD, glare shield, SAC, map case; caused ~5-sec delay

Pilot Could Not Reach Canopy Door Handle

- Small Female could not reach door handle to close canopy door in either AW configuration (C-H or MOPP-OW) or crew station (front and rear)
- Medium Male could not reach door handle to close canopy door in either AW configuration (C-H or MOPP-OW) or crew station (front and rear)
- Large Male could not reach door handle while in the rear crew station (both AW configurations)

SAC – Right Side Egress

- SAC broke off during emergency egress through the right window (2 instances in 16 trials)
- Foot and leg contact with SAC, very difficult to cross over SAC upon egress (4 instances in 16 trials)
- Small Female able to lift legs right over SAC and climb out relatively easily

Difficulties Caused by Personal Weapons

- (Large Male) Pistol gets shifted around to back of calf by SAC, but still accessible.
- (Large Male) Had to rotate pistol counterclockwise to side of right calf to leave; cannot wear pistol on right thigh
- (Large Male) Pistol caught upon SAC; recommend moving weapon to right calf for large males

Helmet and Body Contact with Canopy and Structure

- Helmet contact with front canopy (16 occurrences)
- Helmet contact with top canopy and helmet tracker (5 occurrences)
- Helmet contact with left and right canopy, support struts, or mirrors (8 occurrences)
- When pilot donned helmet in crew station, contact with right mirror and front windscreen. Even with a pilot this small [medium female], significant helmet contact with windscreen

Equipment and Seatbelt Entanglements

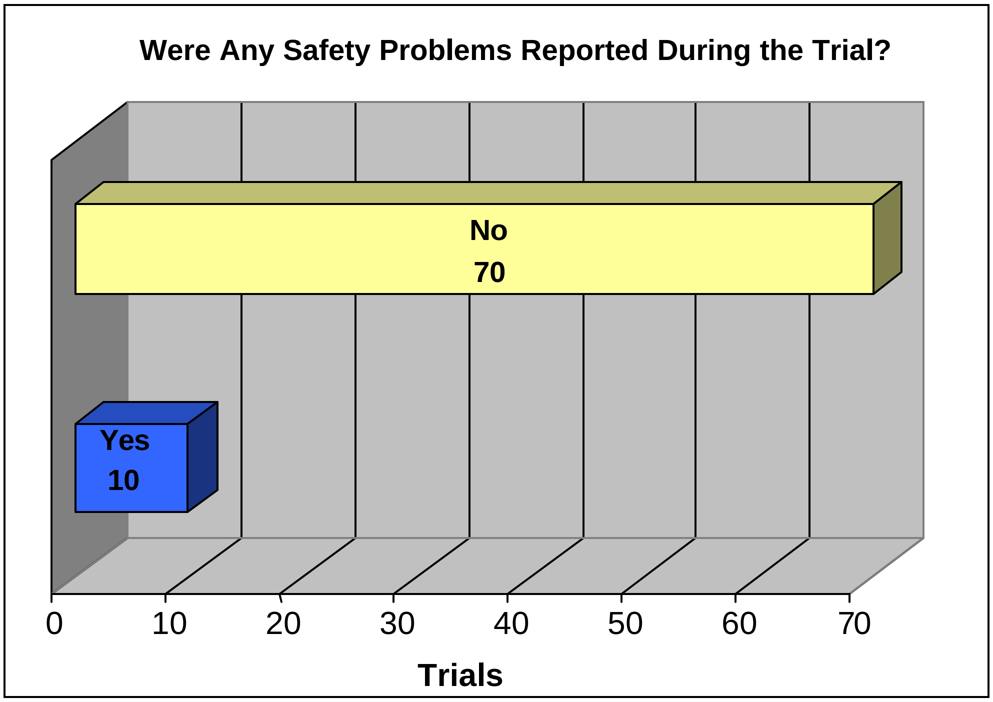
- Restraint harness belts entangled with AW vest and M45 mask hood during emergency egress, typically delaying egress (5 occurrences in 48 trials)
- Right shoulder belt wrapped around straps for the hood; spotters had to free the belts prior to subject falling to the ground

HIDSS cable caught on door handle during egress, caused approx. 4-second delay while spotters freed the cable; subject probably could not have done it. Subject supported weight herself, not by spotters.

Other Comments

- Considerable difficulty in stepping up to or down from rear crew station; reach down to step is blind (6 occurrences)
- New technique for shorter pilots: place mask in helmet, then D-ring the setup to front of AW PSGC. Steps up to back seat, unhooks gear and places in seat, then climbs into the rear crew station.
- "This is stupid; you can't do anything" – Medium Female wearing MOPP-OW in front crew station

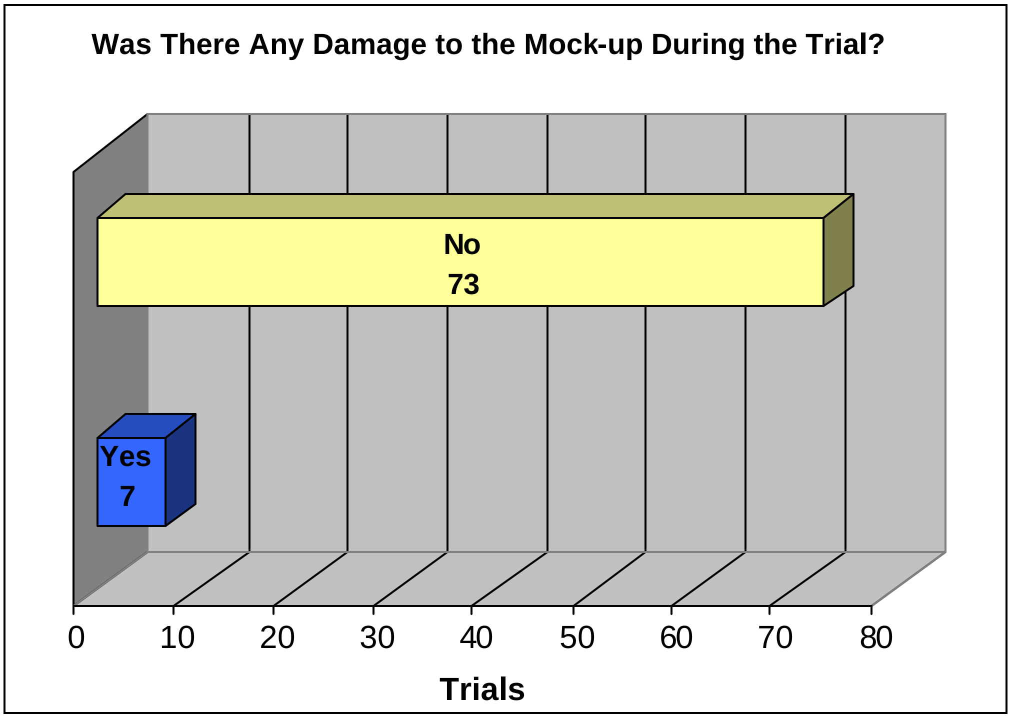
- Emergency egress steps per -10 are all blind (ECLs – off, SPU – off, BATT – off, etc). Just cannot see the switches while wearing the mask. Reported by Medium and Large Males in MOPP-OW.
- Serious difficulties fastening helmet chin strap due to MOPP gloves (2 occurrences)
- Dropped kneeboard to floor but could not reach down to pick up; had to grab between feet and lift it up to hands
- Monocles on HIDSS often did not fit down over eyepieces on the M45 mask (8 occurrences)
- Small Female forgot to push back left armor panel but able to get out anyway



<u>Pilot Comments</u>

- **(LM, Front, C-H)** HIDSS anchor cable on QDC snapped apart during egress—QDC did not work. Pilot actually manually pulled on cable, but did not quick disconnect.
- **(LM, Front, C-H)** Boot soles (ridges) hooked on window sill ledge
- **(SF, C-H, Rear)** Body armor/vest caught on handle and snagged; pilot could not make egress safely without help from spotters
- **(MF, C-H, Rear)** MCG cable got stuck in between seat and SAC box, caused approximately 10-second delay; cable was hanging free in trial, not anchored to the QDC.
- **(LM, MOPP-OW, Rear) C**aught raft on window sill, caused subject to fall straight onto knees in padding
- **(LM, MOPP-OW, Rear)** Seam of trousers and AW straps in crotch area caught upon canopy door handle; weight of ensemble didn't allow me to push up and over handle while sliding over side of aircraft; spotters had to catch me as I fell
- **(SF, MOPP-OW, Rear)** Spotters had to catch subject for safety reasons; she would have hurt herself otherwise
- **(SF, MOPP-OW, Rear)** 6-ft drop to the floor was dangerous but survivable in the MOPP-OW configuration; spotters had to catch me.

- **(MM, MOPP-OW, Rear)** Safety: Left shoulder belt caught between hood and LPFC; spotters had to free it during egress for safety reasons
- **(MM, MOPP-OW, Rear)** Seat belts hung up, delaying egress. Spotters had to support.
- (**LM, MOPP-OW, Front)** Spotters had to support subject upon egress for safety reasons
- **(MM, C-H, Front)** Landed on top of cross-strut beam
- **(MM, MOPP-OW, Front)** - Safety. First attempt of trial, subject wedged helmet between seat head rest and right armor wing panel on egress. Pilot had a more laid-back position to get feet out of left window. As helmet wedged in tight, pilot pulled forward to leave, pulling head out of helmet. Head not allowed to move farther as he hung up on mask/hood straps and seat belt. Likely the subject would not have been able to free himself and leave the aircraft during an emergency. Trial halted at 13 seconds and repeated.



Pilot Comments

- **(LM, Front, C-H)** HIDSS anchor cable on QDC snapped apart during egress—QDC did not work. Pilot actually manually pulled on cable, but did not quick disconnect
- **(LM, Back, C-H)** Helmet drove pretty hard into top canopy and helmet tracker (emergency egress)
- **(LM, MOPP-OW, Rear)** - Right canopy suffered slight contact from helmet
- **(MF, MOPP-OW, Rear)** - Broke off SAC
- **(LM, MOPP-OW, Front)** - Major foot contact with LMPD, glare shield, ECLs, and collective head causing slight damage to mock-up and significantly delaying egress
- **(LM, MOPP-OW, Front)** Helmet struck left canopy support and left mirror
- **(MM, C-H, Front)** Noticed that toggle switches on front seat RWP and LWP have been broken off some time in the past few trials

- **(MM, C-H, Front)** Canopy grab straps must be designed for two-handed use and to support body weight (up to 300 lb), plus a significant jerking force applied to them
- **MM, C-H, Rear)** SAC broke off during egress
- **(MM, MOPP-OW, Front)** Major foot and leg contact (including knife and pistol) on LMPD, glare shield, left map case, and collective. Had to sit on collective head to complete egress.

INTENTIONALLY LEFT BLANK

Acronyms

ABDU	Aviation Battle Dress Uniform
ALSE	Aviation Life Support Equipment
ANOVA	Analysis of Variance
APG	Aberdeen Proving Ground
ARI	Army Research Institute
ARL	Army Research Laboratory
ATEC	Army Test and Evaluation Command
ATTC	Aviation Technical Test Center
AW	Air Warrior
CB	Chemical Biological
C-H	Combat-Hot configuration
CH	Cargo Helicopter
CIK	Crew station Interactive Keyboard
CMM	Coordinate Measuring Machine
DEP	Design Eye Point
DoD	Department of Defense
DT	Developmental Testing
EMD	Engineering and Manufacturing Development
HDU	Helmet Display Unit
HMD	Helmet Mounted Displays
HRED	Human Research and Engineering Directorate
IR	Infrared
IV	Independent Variable
JPACE	Joint Protective Aircrew Ensemble
JSSG	Joint Service Specification Guide
K-W	Kruskal-Wallis test
LM	Large Male
LMPD	Left Mounted Panel Display
MA	Massachusetts
MCG	Microclimate Cooling Garment
MCS	Microclimate Cooling System
MCU	Microclimate Cooling Unit
MD	Maryland
MF	Medium Female
MIHDS	Modular Integrated Helmet Display System
MM	Medium Male
MOPP	Mission-Oriented Protective Posture
MOPP-OW	MOPP-Overwater configuration
M-W	Mann-Whitney U test
NAS	Naval Air Station
NAWC	Naval Air Warfare Center
NBC	Nuclear Biological Chemical
OT	Operational Testing
OW	Overwater
P.I.	Primary Investigator

PM	Program Manager
PMO	Program Manager's Office
RCS	Radar Cross Section
RMPD	Right Mounted Panel Display
SAC	Sidearm Controller
SER	System Evaluation Report
SF	Small Female
SH	Seahawk
STA	Structural Test Article
STD	Standard
STRAP	System Training Plan
TACOM	Tank Automotive Command
TM	Technical Manual
TOC	Table of Contents
TOP	Test Operations Procedure
TR	Technical Report
USAARL	US Army Aeromedical Research Laboratory
USAAVNC	United States Army Aviation Center
USMC	United States Marine Coprs
WSRT	Wilcoxon Signed Ranks Test

NO. OF
COPIES ORGANIZATION

* ADMINISTRATOR
DEFENSE TECHNICAL INFO CTR
ATTN DTIC OCA
8725 JOHN J KINGMAN RD STE 0944
FT BELVOIR VA 22060-6218
*pdf file only

1 DIRECTOR
US ARMY RSCH LABORATORY
ATTN IMNE ALC IMS MAIL & REC MGMT
2800 POWDER MILL RD
ADELPHI MD 20783-1197

1 DIRECTOR
US ARMY RSCH LABORATORY
ATTN AMSRD ARL CI OK TL TECH LIB
2800 POWDER MILL RD
ADELPHI MD 20783-1197

1 ARL HRED AVNC FLD ELMT
ATTN AMSRD ARL HR MJ D DURBIN
BLDG 4506 (DCD) RM 107
FT RUCKER AL 36362-5000

1 ARL HRED AMCOM AVN FLD ELMT
ATTN AMSRD ARL HR MI
BLDG 5464 RM 202 J MINNINGER
REDSTONE ARSENAL AL 35898-7290

1 ARL HRED AMCOM MSL FLD ELMT
ATTN AMSRD ARL HR MO T COOK
BLDG 5400 RM C242
REDSTONE ARS AL 35898-7290

1 ARL HRED USAADASCH FLD ELMT
ATTN AMSRD ARL HR ME A MARES
ATTN ATSA CD
5800 CARTER ROAD
FORT BLISS TX 79916-3802

1 ARL HRED ARDEC FLD ELMT
ATTN AMSRD ARL HR MG R SPINE
BUILDING 333
PICATINNY ARSENAL NJ 07806-5000

1 ARL HRED ARMC FLD ELMT
ATTN AMSRD ARL HR MH C BURNS
BLDG 1002 ROOM 117
1ST CAVALRY REGIMENT RD
FT KNOX KY 40121

NO. OF
COPIES ORGANIZATION

1 ARL HRED CECOM FLD ELMT
ATTN AMSRD ARL HR ML J MARTIN
MYER CENTER RM 2D311
FT MONMOUTH NJ 07703-5630

1 ARL HRED FT BELVOIR FLD ELMT
ATTN AMSRD ARL HR MK J REINHART
10125 KINGMAN RD
FORT BELVOIR VA 22060-5828

1 ARL HRED FT HOOD FLD ELMT
ATTN AMSRD ARL HR S MIDDLEBROOKS
MV HQ USAOTC
91012 STATION AVE ROOM 111
FT HOOD TX 76544-5073

1 ARL HRED FT HUACHUCA FLD ELMT
ATTN AMSRD ARL HR MY M BARNES
2520 HEALY AVE STE 1172 BLDG 51005
FT HUACHUCA AZ 85613-7069

1 ARL HRED FLW FLD ELMT
ATTN AMSRD ARL HR MZ A DAVISON
320 MANSCEN LOOP STE 166
FT LEONARD WOOD MO 65473-8929

1 ARL HRED NATICK FLD ELMT
ATTN AMSRD ARL HR MQ M R FLETCHER
NATICK SOLDIER CTR BLDG 3
AMSRD ARL NSC SE E
NATICK MA 01760-5020

1 ARL HRED SC&FG FLD ELMT
ATTN AMSRD ARL HR MS C MANASCO
SIGNAL TOWERS RM 303A
FORT GORDON GA 30905-5233

1 ARL HRED STRICOM FLD ELMT
ATTN AMSRD ARL HR MT C CHEN
12350 RESEARCH PARKWAY
ORLANDO FL 32826-3276

1 ARL HRED TACOM FLD ELMT
ATTN AMSRD ARL HR MU M SINGAPORE
6501 E 11 MILE RD MAIL STOP 284
BLDG 200A 2ND FL RM 2104
WARREN MI 48397-5000

1 ARL HRED USAFAS FLD ELMT
ATTN AMSRD ARL HR MF C HERNANDEZ
BLDG 3040 RM 220
FORT SILL OK 73503-5600

NO. OF COPIES	ORGANIZATION
1	ARL HRED USAIC FLD ELMT ATTN AMSRD ARL HR MW E REDDEN BLDG 4 ROOM 332 FT BENNING GA 31905-5400
1	ARL HRED USASOC FLD ELMT ATTN AMSRD ARL HR MN R SPENCER DCSFDI HF HQ USASOC BLDG E2929 FORT BRAGG NC 28310-5000
1	ARL HRED FT LEAVENWORTH FLD ELMT ATTN AMSRD ARL HR MP D UNGVARSKY BATTLE CMD BATTLE LAB 415 SHERMAN AVE UNIT 3 FT LEAVENWORTH KS 66027-2326
1	ARL HRED AMEDD FLD ELMT ATTN AMSRD ARL HR MM V RICE BLDG 4011 RM 217 1750 GREELEY RD FT SAM HOUSTON TX 78234-5094
1	ARL HRED SPO ATTN AMSRD ARL HR M M STRUB 6359 WALKER LAND STE 100 ALEXANDRIA VA 22310
1	ARL HRED JFCOM FLD ELMT ATTN AMSRD ARL HR MJF D BARNETTE JFCOM JOINT EXPERIMENTATION J9 JOINT FUTURES LAB 115 LAKEVIEW PKWY STE B SUFFOLK VA 23535
1	US ARMY SAFETY CTR ATTN CSSC SE FORT RUCKER AL 36362
	<u>ABERDEEN PROVING GROUND</u>
1	DIRECTOR US ARMY RSCH LABORATORY ATTN AMSRD ARL CI OK (TECH LIB) BLDG 4600
1	US ATEC RYAN BLDG APG-AA
1	DIRECTOR US ARMY RSCH LABORATORY ATTN AMSRD ARL CI OK TP S FOPPIANO BLDG 459
1	DIRECTOR US ARMY RSCH LABORATORY ATTN AMSRD ARL HR MB J NAWLEY BLDG 459
1	DIRECTOR US ARMY RSCH LABORATORY ATTN AMSRD ARL HR M F PARAGALLO BLDG 459
1	DIRECTOR US ARMY RSCH LABORATORY ATTN AMSRD ARL HR SE S HILL BLDG 459